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RUDIMENTARY TREATISE

ON THE

METALLURGY OF COPPER.

BY

R. H. LAMBORN, M.I.R.G.R. Vienna,
&c. &c. &c.

With Illustrations.

LONDON: JOHN WEALE.

THE

METALLURGY OF COPPER.

A RUDIMENTARY TREATISE

ON THE

METALLURGY OF COPPER.

BEING A

CONCISE INTRODUCTION

TO THE

METHODS OF SEEKING, MINING, DRESSING, ASSAYING,
AND SMELTING THE ORES OF COPPER AND
MANUFACTURING ITS ALLOYS;

TOGETHER WITH HISTORICAL AND STATISTICAL NOTICES
OF THE METAL.

BY

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PREFACE.

The Anglo-Saxon nations exceed all other in the value and amount of the metals and minerals they each year bring into commerce, yet their literature treating of the methods by which these subterranean treasures are raised and made valuable is small and unsatisfactory.

The Author does not expect within the compass of a Treatise of this size to do much towards extending that literature, but he ventures to believe that by furnishing in a condensed form, the principles of the metallurgy of copper, and a description and explanation of the latest and most important means of discovering and reducing the ores of that valuable metal, step by step, to a condition suited for the purposes of the manufacturer,—he will supply a source of information for which English smelters, students, and artisans, have long sought.

In concluding this volume the Author cannot omit returning his thanks to the owners and officers of various mines and furnaces upon this and the other side of the Atlantic for the uniform courtesy they have extended to him, and to mention the following excellent works and papers from which he has drawn material in the preparation of the accompanying chapters:

Muspratt's "Chemistry applied to the Arts."
Phillips' "Manual of Metallurgy."
"Napier," in the "London, Dublin, and Edinburgh Philosophical Magazine," vols. iv., v.
"Clark," in "Journal of Society of Arts. 1858."
Hunt's "Mining Records."
Whitney's "Metallic Wealth of the United States."
Kerl's "Handbuch der metallurgischen Hüttenkunde."
Zippe's "Geschichte der Metalle."
Von Cotta's "Lehre von den Erzlagerstätten."
Bodemann's "Anleitung zur Probirkunst."
Scheerer's "Lehrbuch der Metallurgie."
Plattner's "Vorlesungen über Allgemeine Hüttenkunde."
Plattner's "Probirkunst mit dem Löthrohre."
"Métallurgie du Cuivre par Rivot."
"Le Play, Procédés Metallurgiques dans le pays Galles."
"Moissenet, sur le procédé Anglais pour les Essais de Cuivre."

FREIBERG, SAXONY, *July 4th*, 1860.

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THE

METALLURGY OF COPPER.

PART I.

GENERAL CONSIDERATIONS REGARDING COPPER; HISTORY; PHYSICAL AND CHEMICAL PROPERTIES; MINERALOGICAL AND GEOLOGICAL RELATIONS; MINING; ASSAYING; GENERAL METALLURGY; FUELS AND APPARATUS USED BY THE COPPER SMELTER.

CHAPTER I.

HISTORICAL SKETCH OF COPPER.

COPPER is one of the six metals spoken of in the Old Testament, and one of the most important of the seven mentioned by ancient historians. It was known at least as early as the time of Tubal Cain, since he was an instructor of artificers in brass and iron. Grecian historians relate that Cadmus discovered copper, and taught its application to the wants of mankind. It was found on the island of Eubœa, near the town of Chalkis, and hence it has been assumed came the Grecian name *Chalkos,* by which the metal was known to Homer, Hesiod, and other ancient Achaean authors. The Romans knew copper as *aes cyprum,* and later as *cuprum,* names derived from that of the island Cyprus, where Pliny declares the method of working it was discovered. It is certain that upon this island the Phœnicians had opened mines at a very early date. Hence in the mystic nomenclature of the Alchymists copper came to be called *Venus*, to which goddess Cyprus was sacred, and among their signs it was known by the astronomical designation of that planet ♀. The English word *copper*, the French *cuivre*, and the German *kupfer*, were introduced into those languages during the middle ages, and are plainly but alterations of the Latin name.

The mention of copper in the oldest records, and among the first metals whose use was known to mankind, is consistent with what we would be led to conclude, after a close consideration of its nature and the manner of its occurrence. Masses of the tough native metal, detached by water from their original beds, and deposited in spots where a warlike people went to seek stones from which to shape their rude weapons, by reason of their weight, colour, lustre and malleability, would quickly attract attention. These qualities, connected with the fact that the native masses are often of considerable size, render it more than probable that copper was the first metal upon which were made the unskilled attempts of primeval smiths and smelters.

In the Hebrew manuscripts no distinction is made between pure copper and the alloy with tin, which in modern times has been known as bronze, but which in our translations is rendered by the word brass. This alloy, however, was undoubtedly the discovery of a generation long posterior to that which made the earliest use of native copper, since tin not being found in the countries bordering on the shores of the Mediterranean, could only have been introduced after commercial relations with distant European or Asiatic regions had been established. It is generally assumed, without any particular evidence to support the assumption, that the ancients had a means of making this alloy of tin and copper so hard that it would cut the most refractory rocks, and the existence of vast monuments of syenite and porphyry are spoken of by antiquaries as inexplicable under any other supposition.

It is a fact provoking speculation, that the race of the Incas in Peru, although unable to reduce the iron ores that were scattered in abundance around them, and hence ignorant of the use of that metal, were well aware of the peculiarities of this hard alloy of copper and tin, and forming it from proportions almost identical with those adopted by the ancients of the old world, used it to construct the tools required for dressing the stones necessary in building their vast aqueducts and temples.

The Israelites had bronze weapons in the time of David. Homer represents his heroes fighting with arms made from the same substance, and it formed an important portion of many of the agricultural implements of the ancients. Bronze was early recognised as a material adapted to the needs of the fine arts; the Colossus of Rhodes, which was constructed of this metal, is a remarkable proof of the abundance of copper even at that early date; and it is said that Mummius, after the sacking of Corinth, filled Rome with bronze statues, thus transporting Grecian art to the banks of the Tiber. Whether the Phœnicians who carried tin from Britain found there the knowledge of making bronze, is uncertain; but it is a probable hypothesis, that the enigmatical weapons and tools of bronze found in the graves of some ancient race in various European lands, and which archæologists have determined to be Celtic remains, were obtained by the wandering tribes from that region in Britain where at the present day the descendants of those same metallurgic Celts have made themselves the largest refiners of copper on the globe, and in whose vicinity occurs the richest and almost the only known tin region within a circumference of many thousands of miles.

The earlier money of the Romans was of bronze, or more rarely of the alloy of copper with zinc, known as brass. Before the time of the Cæsars no pure copper pieces appear to have been struck, and those of the time of the emperors often show indications of having been silvered, by which process it is probable they were made to take the place of solid pieces of the more valuable metal.

Descending into the middle ages, we find a new and important application of copper in its combination with tin originating in the triumph of the Christian religion. Church bells, which are made of this alloy, are first definitely mentioned in ecclesiastical records of the seventh century; they were brought into general use by Charlemagne, and for several centuries were almost the only object for the employment of the founder's art.

In the construction and ornamenting of churches, copper, bronze, and brass, have played an important part: the roof, the altars, and the sepulchral monuments were often wrought of these substances; and the statues and decorations of pantheistic temples still exist in renovated forms in the worshipping places of Christendom. The invention of gunpowder, and the subsequent introduction of bronze cannon in the wars of the fourteenth and fifteenth centuries, had an important influence in increasing the value and the production of copper; and as the civilisation of more modern periods grew, the demand for a cheap metal, approaching in its properties those of gold and silver, increased rapidly, until at present there is scarcely a branch of human economy where copper is not found an important means of arriving at greater perfection. Either unmixed or in the form of a compound, it is employed in the construction of nearly all kinds of machinery; for forming the delicate instruments of the astronomer, natural philosopher, engineer, and musician; for increasing the security of commercial enterprise by adding to the durability of ships; as a path for the electric current in its bold journey from continent to continent in the service of civilisation. It furnishes a re-agent for the chemist, and for the physician a remedy against disease. The sculptor employs it to express his conceptions, the painter, aided by the engraver, to reproduce and disseminate his beautiful thoughts. The electro-metallurgist uses it to catch and make prominent the evanescent forms of nature and art. The glassmaker, the cook, the dyer, and those engaged in many other employments, use it constantly, while almost every advance made in technical science adds to the number of its applications.

Eubœa and Cyprus have already been mentioned as localities known to the ancients for their mines of copper-producing minerals. The Egyptians in early times drew their supply of the metal from Arabia, and it is related that one of the objects in view by Ramses the Great, in digging the canal across the isthmus of Suez, was to connect the copper-producing countries of the Arabian peninsula with his kingdom on the Nile.

Travellers of the present day find in the midst of the waste, far removed from the region of fuel, remains of mines, and hieroglyphic inscriptions proving them to belong to an age almost beyond the reach of history.

Upon the highlands of the Urals and the Altai are found remains of mines dating from the most remote period, before the use of iron was introduced as a material for the construction of tools. The Phœnicians brought copper from Asia Minor, the Taurus Mountains, England, Portugal, and Spain, and during the middle ages the last-mentioned countries produced a notable quantity of the metal under consideration.

At the present time copper is furnished from a vast number of localities in every quarter of the globe. The United Kingdom however ranks before any other country in the amount of ore raised and the weight of metal reduced. The information we have regarding the early stages in the progress in Britain of both the mining and metallurgic divisions of this important branch of industry, is remarkably scanty, and records or traditions treating of the period prior to the beginning of the seventeenth century, are seldom of a reliable character.

At Newlands, near Keswick in Cumberland, some rich mines of copper were wrought about 1250, and it would appear that in 1470 the place was still famous for the metal it produced. Ecton Hill, in Staffordshire, was another spot where copper was obtained in considerable abundance, previous to the era of copper mining in Cornwall.

It is amusing, with our present knowledge of the mineral resources of England, to meet with Acts of Parliament passed in the reigns of Henry VIII. and

Edward VI. for preventing the exportation of brass and copper, "lest there should not be metal enough left in the kingdom fit for making guns and other engines of war, and for household utensils;" and even at so late a date as 1708, to find a memorial presented to the House of Commons by the brass manufacturers, stating that "England by reason of the inexhaustible plenty of calamine, might become the staple of brass manufacture for itself and foreign ports, and that the continuing the brass works of England would occasion *plenty of rough copper to be brought in.*"

At this period the supply of copper came from the continent, metal produced by the mines of the Hartz and Hungary was sold in the magazines of London, and indeed not until 1717 were English pennies struck from English metal. At the end of the seventeenth century the attention of Cornish tin miners began to be seriously drawn to the more valuable cupreous deposits around them; previous to that date, it is true, copper ore had been sold at a low price under the name of *poder*, but this was produced by mines worked or originally opened for tin. The yellow copper pyrites was the first ore recognised as valuable by the miner, the far richer sulphide and black oxide of copper were for a long time not considered worth preserving, and thousands of pounds were cast into the sea or left standing in the lodes to surprise and delight subsequent and wiser explorers. Deposits began to be opened exclusively for the copper they contained, about the commencement of the last century, and from that time to the present the produce of ore has gradually but steadily increased. The discovery of the rich mines of Anglesea in 1768, the addition of Devonshire and Ireland to the list of copper-producing regions, and of late years the immense importation of ores from Chili, Cuba, and the Pacific islands, have neither destroyed the demand for Cornish ore nor materially disturbed the law of growth.

The advantage of sending ore to be smelted in the rich repository of fuel in the Welsh coal basin was very early perceived, and even in 1586, according to Carew, ore was shipped thence from Cornwall. In 1765, several furnaces were in existence near Bristol, and others along the coast toward the westward. The general plan of the various processes then in use appears to have been extremely similar to that now practised at Swansea, and known as the English method of smelting copper; and when we consider the complex nature of the numerous operations which it includes, and the remarkable difference that exists between them and those practised at that time in all other copper-refining countries, we cannot but admire the ingenuity and judgment of those old metallurgists who, aided only by their clear powers of observation, worked out a system which, while it is so excellently adapted to all the circumstances of the locality, can be used in the treatment of every known variety of ore, and has withstood, with but slight changes, the keenest researches of modern science.

In the United States of America copper in workable quantities has been found in nearly all the States penetrated by the Appalachian chain of mountains. The oldest incorporated mining company in the country appears to have been one for the purpose of working copper ores in Connecticut, the date of whose charter is 1709. But all other deposits at present sufficiently developed to warrant a judgment regarding their value are exceeded by that which, within the last sixteen years, has been re-opened upon the shores of Lake Superior. That this remarkable region was known to a race existing at a period anterior to the earliest authenticated dates in aboriginal history, is evident from the remains which still exist of gangways, tools, and other proofs of skill which the races occupying the country at the time of its discovery nowhere evinced. The Indians found by the first travellers were utterly ignorant of the methods of working that had been in use by the former race; they had no traditions to explain the existence of the numerous excavations, and what copper they possessed was only such as they gathered among the surface stones. The first record of the deposit is found in the missionary report of the Society of Jesuits for 1659-60. The savages had then rude utensils made from the metal, and huge blocks of it were erected and worshipped among their gods. In 1763, one Henry, a practical Englishman, explored the country at the imminent risk of his life, and in 1771 he established works, which were, however, soon abandoned.

The recent mining era of the region begins with the year 1844. The explorations of various scientific men had made the region partially known to the world, and miners drawn thither by the reports of mineral wealth, soon discovered large blocks of the native copper, containing much silver. A feverish excitement set in among adventurers and capitalists, and companies were formed in various parts of the world to work localities, of which, in many cases, not even a survey had been made. In 1847, the inevitable crisis came, and of the hundreds of companies nominally existing, only six were found actually engaged in mining. The distrust naturally resulting from these early disasters has gradually disappeared. The convulsion was beneficial in exposing the spurious and worthless schemes, and in pointing out those enterprises whose inherent strength made them capable of weathering the storm. Since that period the progress of the region has been healthy, legitimate, and unwavering.

CHAPTER II.

ON THE PHYSICAL AND CHEMICAL PROPERTIES OF COPPER.

COPPER differs from all other metals in possessing a red colour; its hue, however, is not to be confounded with the deeper red,—known in common language as "copper-red"—that may often be seen on the surface of copper vessels, and which results from a coating of the suboxide. In thin leaves, copper permits the passage of light through it, and the colour transmitted is a beautiful green. Like many of the uncombined metals, it crystallises in cubes or octahedrons, which forms are not uncommon in natural specimens, and may be obtained by precipitating the metal from a solution by galvanic action. Its specific gravity, or weight, compared with an equal bulk of water, varies according to the manner in which it is treated,—thus:—

When cast it lies between 8·59 and 8·90
When hammered between 8·88 ,, 9·00
When in the form of wire 8·78 ,, 8·95
A piece cut from the centre of a mass of native metal, 8·838

In regard to weight, therefore, it occupies a medium position among the common metals; gold, lead, and silver being heavier, and iron, tin, and zinc lighter. It is superior to all the other common metals, except gold and silver, in its malleability, or the facility with which it allows itself to be hammered into thin sheets, but beside these, the two metals iron and nickel exceed it in ductility, or the property necessary for producing fine wire. It ranks with gold and silver in hardness, is sonorous, and forms a part of some of the most sonorous compounds with which we are acquainted. When warmed, or rubbed, it gives off a disagreeable smell, and its taste is faintly nauseous and metallic. Copper melts at a strong red heat, according to the recent determinations of Plattner at 2143° Fahrenheit, or somewhat above the melting-point of silver and gold, and when in a fluid condition appears of a sea-green colour. Upon being raised to a white heat it volatilises slightly, and combining with the oxygen of the air, burns with a greenish flame. When pure it retains at all temperatures below the smelting-point, a high degree of ductility, and the hardness and brittleness which are produced in it by rolling and hammering may be removed by heating. In tenacity, it ranks next to iron; a wire ·787 of a line in diameter sustaining a weight of 302·3 pounds. Its power of conducting heat is a little more than 2½ times that of iron. Its linear expansion, when heated from 32° to 212°, is 0·001879, and it ranks with silver above the other metals in its capacity for conducting electricity.

The chemical symbol of copper is Cu, from the Latin name *cuprum*. The proportion with which it combines with other elements indicates that its atomic weight is

31·71 times that of hydrogen; or when oxygen is assumed as 100, its equivalent number is 396·7.

Chemically pure copper may be obtained by heating the oxide in a glass tube, through which a stream of hydrogen gas is passed; the oxygen leaves the copper, and combines with the hydrogen, forming water, which is carried off, and the pure metal in the form of a powder remains behind. Copper which is precipitated from a pure solution, through electro-galvanic action, by a means hereafter to be described, is also chemically pure. The "best selected copper" of the Swansea furnaces is almost absolutely pure; the "tough copper" and the "tile copper" contain traces of arsenic, nickel, tin, iron, and sulphur, altogether, however, seldom amounting to more than 0·008, or $\frac{4}{5}$ths of one per cent. The Russian copper generally contains some iron, although otherwise exceedingly pure;* that from the native metal of Lake Superior is frequently very free from foreign substances, some analyses, however, show an admixture of as much as 0·0003 silver; the South American commercial copper is often mixed with scraps of iron and the constituents of the ore.

By common temperatures copper remains in dry air

---

* The following analyses show the composition of several continental commercial coppers :—

REFINED COPPER.

	Copper. per cent.	Silver. per cent.	Iron. per cent.	Lead. per cent.	Tin. per cent.
From Norway, analysed by Genth .	99·61	trace	0·62	trace	0·27
,, Freiberg, Saxony . . .	98·92	0·032	0·00	0·63	0·00

ROSETTE COPPER.

	Copper. per cent.	Lead. per cent.	Iron. per cent.	Nickel. per cent.	Antimony. per cent.
From the Hartz, analysed by Bodeman	98·48	trace	0·75	0·26	0·76
,, Sweden, analysed by Genth .	99·55	0·19	0·15	0·00	0·00
,, China, No. 1, analysed by Onner	97·79	0·00	0·21	1·35	0·50

unchanged, but in contact with moisture, or in the presence of acid vapours, it becomes coated with a green scale called verdigris. Upon the slight affinity, when compared with other metals, possessed by copper for oxygen, rest some of the most important processes in its metallurgic treatment; the following series, arranged as nearly as possible in the order of the strength of this affinity, shows how close, in this respect, it stands to the precious metals; 1. iron, 2. zinc, 3. lead, 4. cobalt, 5. nickel, 6. copper, 7. tin, 8. silver, 9. gold.

At a white heat copper decomposes water into hydrogen and oxygen; the latter element then combines with the metal and an oxide is produced. Weak acids, as for instance vinegar, have no influence on copper except in the presence of air, hence there is no danger in cooking acid food in vessels formed of it provided they are kept perfectly bright, since the vapour which passes off forms a complete protection from the surrounding atmosphere; but it is dangerous to allow the food to cool in these vessels, because the air then gains admission and a soluble and poisonous metallic salt is quickly formed. In a state of fine division copper is a little dissolved by hydrochloric acid, while in larger masses this re-agent scarcely affects it. Strong sulphuric acid dissolves it when warm, developing stifling fumes of sulphurous acid. But nitric acid is its proper solvent: by this re-agent it is reduced at common temperatures, with development of copious red fumes of hyponitric acid, to a blue solution of the nitrate of copper.

Copper unites with most of the elements in various proportions; it will be appropriate here to describe only the most important combinations.

In combination with oxygen. When copper is heated in the air it becomes gradually coated with a red film of the sub-oxide, which passes gradually into the black or the protoxide. Both of these compounds are moderately strong bases, that is to say they combine readily with acids forming salts. The suboxide has the formula $Cu_2 O$, and is composed of

88·80 parts of copper,
with 11·20 parts of oxygen.
———
100·000

It is found in nature beautifully crystallised in regular octahedrons, and is an important ore of the metal. When melted with quartz it gives to the resulting compound a brilliant red hue, which resembles that of the ruby.

The black or protoxide of copper has the formula $Cu O$, and is combined as follows:

79·85 parts of copper,
with 20·15 parts of oxygen.
———
100·00

It may be readily formed by heating nitrate of copper in the air; when thus produced, it is a black powder, which rapidly absorbs moisture from the atmosphere. This is also a mineral from which copper is metallurgically won, and it occasionally occurs in large masses.

By the solution of this oxide in various acids, a series of salts may be formed, all of which have, while containing water, a blue or green colour; but which, when they lose their water, become a dirty white. A solution of any of these compounds may be recognised by the following reactions:—

Ammonia gives at first a greenish precipitate, but as more of the re-agent is added, a deep blue colour is produced. The ferrocyanide of potassium throws down a brownish red precipitate, which becomes reddish purple when the solution is very much diluted. This reaction is so delicate that the smallest traces of a soluble copper salt may be detected, when there is no substance at the same time present which renders the characteristic colour invisible, as for instance iron. A clean plate of iron or zinc, when dipped in a solution of a salt of copper, becomes coated with the latter metal, which means of discovering its presence is very convenient and quite delicate.

The most common of the copper salts are: *Sulphate of copper* or *copper vitriol*, $\mathrm{Cu\,O, SO_3 + 5\,HO}$. This is largely used in the process of dying and in electro-metallurgy, and is the substance from which nearly all the other chemical compounds of copper are produced. It is held in solution by the water flowing from many mines, and the metal is frequently reduced from it by a process to be described further forward. *Carbonate of copper* or *Malachite*, $\mathrm{Cu\,O, CO_2 + Cu\,O, HO}$, and *Azurite*, $\mathrm{2\,Cu\,O, CO_2 + Cu\,O, HO}$, are found among the ores of copper, and are also manufactured by a secret process and brought into trade as colours; the first as "mineral green," the second as "mountain blue;" but both are liable to change their shade by dampness or bad air. The compound of the oxide of copper with acetic and arsenic acids produces the "Schweinfurt green" of commerce. It is one of the most violent poisons, and is frequently used in the manufacture of paper hangings.

The compounds of copper with sulphur. Among the common metals, when in a melted condition, copper has the strongest disposition to unite with sulphur; next to it comes iron, then in the order of their attraction: tin, zinc, lead, silver, antimony, and arsenic. To the metallurgist this varying affinity is of the utmost value in furnishing him a means of separating, more or less completely, one member of the series from another. Copper burns with a brilliant light when heated in the vapours of sulphur, producing the *sub-sulphide* $Cu_2 S$, which substance occurs in nature and is known as copper glance. The compounds of copper with sulphur are in their natural state generally mingled or combined with the sulphides of iron, forming, as will be seen by a reference to the mineralogical section of this treatise, the most important ores of the former metal.

The *sulphide of copper*, $Cu S$, is produced artificially by decomposing the oxide with sulphuretted hydrogen; it is a dark powder, which if left exposed to the air rapidly absorbs oxygen.

With chlorine and iodine copper unites in proportions analogous to those of the oxygen compounds.

All the soluble salts of this metal are poisonous, though in small doses they are occasionally administered as tonics, anti-spasmodics, or alteratives, but when taken in larger quantities they occasion inflammation, and disorder the functions of the nervous system. The symptoms in cases of poisoning by copper are, a cupreous taste, violent vomiting, cramps in the legs and thighs, giddiness, convulsions, and insensibility. The best antidote is albumen or white of egg: if administered in large quantities milk will answer the same purpose. The compounds known as *alloys,* formed by the combination of copper with one or more of the other metallic elements, are so numerous, various, and important, that a separate chapter has been devoted to a description of their preparation, nature, and use.

CHAPTER III.

The Blowpipe, its Accompanying Instruments and Re-Agents; Method of using them to Detect, and Determine the Nature of Copper Ores.

The external characteristics of the substances which continually demand the attention of the practical metallurgist in the form of ores, fluxes, slags, &c., are, in the majority of cases, entirely inadequate to enable him to determine either their commercial value, or the processes to which they may be the most profitably submitted. A knowledge of their chemical nature—of their worthful or disadvantageous elements—is alone capable of leading to this necessary information. Few of those connected with smelting have the time to spare to make themselves good chemists, since to become such requires years devoted to this especial study. But the copper smelter has his attention called to but a limited number of substances, and comparatively to but a few processes, and hence the amount of chemistry absolutely necessary for him to understand is limited.

By the labours of modern experimenters, an instrument has been perfected which seems to be the natural assistant of the metallurgist; since by its aid, and without the possession of extended theoretical knowledge, he is enabled to perform on a small scale, and while the substance acted upon is beneath his close observation, many of the same operations which his business requires him to carry out, in his furnaces and smelting-pots.

This instrument is the *blow-pipe,* which, with its essential accompaniments, furnishes the experimenter with a powerful but delicate blast-furnace that is under the most perfect control, and is capable, in a very short time, with the aid of a few simple re-agents, of proving the presence or absence of nearly every substance likely to be found among the constituents of ores. The fact that the blow-pipe and its necessary suite of instruments and re-agents are so easily obtained, and so compact, and that the ordinary student may gain (without the aid of a teacher) a considerable skill in their use; and further that their applications are so numerous, and the results obtained so trustworthy, that they are often capable of taking the place of a complete chemical laboratory,—makes their description, and directions for their use, in a work like this, especially appropriate.

The efforts of Bergman, Berzelius, Harkort, Plattner, and others, have gradually raised the blow-pipe from its original position as a tinman's tool to its present scientific importance, and made it not only applicable to the discovery of the elementary constitution of compounds, or to *qualitative analysis,* but have given it a high value as furnishing a means of executing certain *quantitative analyses,* or determining the amount of metal which a given compound may hold. The metals that by this process may be most accurately separated and estimated, are silver, gold, lead, copper, tin, bismuth, cobalt, and nickel.

Following will be found a description of the apparatus, re-agents, and methods necessary for discovering the nature of those ores, slags, or mineral mixtures which will be likely to be brought to the attention of the copper smelter; and in Chapter VI. the quantitative method will be given, with sufficient detail to enable a careful workman to determine the amount of copper present in any given compound.

DESCRIPTION OF APPARATUS.

The best form for a blow-pipe is that shown in the accompanying figure. It should consist of a tube, *a b*, 7½ inches long, having at one end a mouth-piece of horn, *f*, shaped like the extremity of a trumpet. At the other end the tube fits with a ground joint into a cylinder, *b c*, which serves to retain the moisture of the breath. Into this cylinder a small tube, *d e*, is fitted in the same manner; and to the end of this tube, by a third ground joint is attached the platinum point, *e*, of which a full-sized longitudinal section is given at *g*. The opening at *h* should have a diameter of ⅕ of a line. With the exception of the two ends, the entire instrument may be made of brass or German silver.

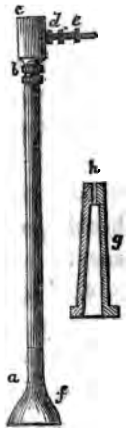


FIG. 1.

2. The best instrument for supplying the required flame for blow-pipe use is that represented by fig. 2; but in many cases of qualitative testing, a common

wax, stearine, or tallow candle will answer every purpose. The following dimensions for a blow-pipe lamp will be found convenient: *a b* = 5 in.; *c d*, 1¼ in.; *e f*, 9 in.; *g h*, or the breadth of the wick, ½ in. The vase of the lamp, *a b*, may be of japanned sheet-iron. The remaining portions of the instrument should be of brass or German silver. The portion *k*, which answers the purpose of a stand upon which small vessels may be placed to be treated, can be taken off when the lamp is otherwise in use. The wick should be of cotton, and must be kept cleanly and evenly trimmed. As a burning material, refined rape seed or olive oil may be used, or, what is still better, a mixture of one part of oil of turpentine with twelve parts of strong spirits of wine.

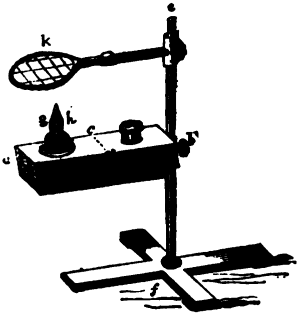


FIG. 2.

3. Beside this oil-lamp, a small *alcohol lamp* for heating substances in glass tubes will be found necessary.

4. *Platinum wires*, about $\frac{1}{5}$ of a line in diameter, and 2½ inches long, used for holding substances while being melted with borax and other glass fluxes. They should be curved at one end into a loop, that the bead which adheres to them may be more securely held.

5. *Glass tubes closed at one end*, about ¼ inch in diameter, and 3 inches long, and made of thin glass, that they may not break in the heat. These are used to heat substances in, over the alcohol lamp, in order to

determine the presence of water, sulphur, arsenic, and other volatile elements.

6. *Glass tubes open at both ends*, about ¼ inch in diameter, and 4½ inches long, also made of thin glass, for the purpose of observing the effects of the air upon substances exposed in its presence to a high temperature. A bit of the substance to be tested must be placed in the tube, which is then held at a slight angle with the horizon, and heated over the alcohol lamp.

7. *Forceps* of brass or German silver, with platinum points, for holding splinters of a mineral in the flame while determining the colour produced by a high heat, and the smeltability.

8. A small smooth *block of steel* and a small *hammer*, for proving the malleability of globules and breaking minerals.

9. A number of pieces of well-burned homogeneous *charcoal*, made from fine-grained wood.

10. A small *magnet*, to test for iron, nickel, and cobalt.

11. Beside the above, it will be found useful to possess several small and thin porcelain dishes, two or three glass funnels, a small flask for holding water, a wooden stand for test tubes and one for filtering, and a quire or two of filter paper.

RE-AGENTS.

These should be kept in small glass bottles with ground stoppers.

1. *Soda* (carbonate of soda): for reducing metallic oxides to the condition of metals, and for determining the presence of sulphur and silica.

2. *Neutral oxalate of potash* furnishes a still more efficient means of reducing the metallic oxides.

3. *Borax* (biborate of soda) has the property of forming a transparent glass, which becomes variously coloured by the addition of different substances.

4. *Salt of phosphorus* (phosphate of soda and ammonia) is used in the same manner as borax, but often produces a peculiar reaction. Nos. 3 and 4 are sometimes called the glass fluxes.

5. *Bisulphate of potash,* for testing for the presence of boracic acid, chlorine, nitric acid, &c.

6. *Saltpetre* (nitrate of potash), for testing for manganese.

7. *Nitrate of cobalt,* in solution, for distinguishing between magnesia and alumina, and zinc and tin.

8. *Pure lead,* for the gold and silver assay.

9. *Finely-powdered bone ash,* to be used for absorbing the oxide of lead in the gold and silver assay.

10. *Sulphuric acid, hydrochloric acid, nitric acid,* and *ammonia.*

MANAGEMENT OF THE BLOWPIPE AND FLAME.

The student of blow-piping having possessed himself of the apparatus and re-agents that have been mentioned, is ready to begin his experiments. His first efforts must be addressed to learning to produce a steady blast, and to generate and distinguish between the different sorts of flames. The operation of blowing should not be performed by means of the lungs, but with the muscles of the cheeks, the air is furnished as required to the cavity of the mouth, but breathing should proceed undisturbed through the nose.

The flame of the blow-pipe, possesses besides the property of furnishing a very strong heat, that of acting as a powerful chemical re-agent, and as such it must be chiefly studied.

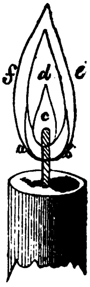
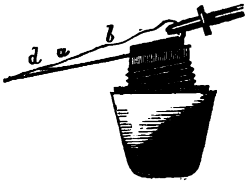


FIG. 3.

When we examine the flame of a common candle, we discover that it is composed of four parts. At the base a small cresent *a b* with a clear blue colour; higher up and in the centre of the flame, the dark conical portion *c*, surrounding this is the luminous portion *d*, and exterior to the two last is the scarcely perceptible mantle *f e*. The student has to remark the nature of two of these divisions: the exterior non-luminous part *f e*, which is composed of gases already saturated with oxygen, that under certain circumstances goes over to bodies with which the flame is brought in contact, and hence constitutes the *oxidizing flame;* and secondly, the luminous portion *d*, which consists of gases not yet saturated with oxygen, and therefore capable of extracting that element from easily reducible oxides, and hence called the *reducing flame.*

FIG. 4



When the point of the blow-pipe is held about one-third of the breadth of the wick in the lamp flame, as in fig. 4, a flame is produced by blowing that is long, slender, and blue, is hottest at the outermost point *a*, and is an *oxidizing flame.* This action, however, is strongest slightly beyond *a*, about *d* in the stream of heated gas.

If now the point of the blow-pipe be held as in

FIG. 5

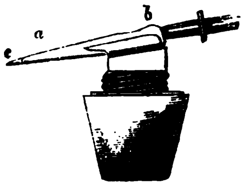


fig. 5, somewhat higher than before, and ~~not~~ quite within the flame, a larger and more luminous cone of burning gases may be driven in the direction *b c*; within the bright portion of the flame at *a*, the above mentioned chemical action on oxides takes place, which causes this to be called the *reducing flame.*

EXAMINATION OF MINERAL COMPOUNDS.

The student may now commence the examination of the mineral substances, the composition of which he wishes to discover. In this examination it is usual to pursue a regular course as follows:—1st. Heating the mineral in a closed glass tube such as is described on page 20. 2nd. Heating in an open tube, page 21. 3rd. Trying in forceps before the oxidising flame to discover the colour of the light produced. 4th. Heating the substance alone on coal to observe whether it is volatile, and what kind of a sublimate it forms, and moistening the substance or sublimate with cobalt solution to bring out a characteristic colour. 5th. Melting with borax and salt of phosphorus (glass fluxes) upon platinum wire, to observe the colours produced. 6th. Tests in the humid way with acids and other reagents.

During this course of experiments, phenomena will generally be observed which will decide the nature of the substances present. The distinguishing characteristics in the behaviour of those metals or metalloids that will be likely to be found during the examination of minerals containing copper, or in the fluxes used in its metallurgic treatment, are given briefly in the following list.

BEHAVIOUR BEFORE THE BLOWPIPE OF SUBSTANCES LIKELY TO BE MET WITH BY THE COPPER SMELTER.

1. *Sulphur;* when heated in an open glass tube, ores containing sulphur generally give off fumes of sulphurous acid, similar to those perceived when a common match is lighted. If a substance containing sulphur be melted with pure soda, and the mass brought upon a clean silver coin and moistened with water, a dark spot is formed.

2. *Selenium;* when a small fragment of a mineral containing selenium is heated on charcoal, an odour is observed similar to that of rotten horse-radish.

3. *Phosphorus* gives when the substance that contains it is moistened with sulphuric acid and held in the forceps, a green tinge to the flame.

4. *Chlorine.* By saturating a bead of salt of phosphorus on a platinum wire with the oxide of copper, and then adding the mineral supposed to contain chlorine, in case of its presence a deep blue colour will be given to the flame.

5. *Fluorine.* By heating a substance containing this element in a glass tube with salt of phosphorus, the interior surface of the glass becomes etched or roughened.

6. *Silica* (*Quartz*) when heated strongly with salt of phosphorus on a platinum wire, swims in a skeleton-like fragment in the bead.

7. *Arsenic* in its various compounds give a garlicy odour, and a white vapour when heated on charcoal.

8. *Antimony* gives upon charcoal a white sublimate, but developes no *odorous* fumes.

9. *Copper* gives with borax upon platinum wire and in the oxidation flame a greenish bead, which on cooling becomes blue: in the reducing flame this bead becomes red with the suboxide. When its solution in acids is saturated with ammonia, a beautiful and unmistakeable deep blue colour is produced.

10. *Bismuth* gives on charcoal, a sublimate which while hot is dark orange-yellow, but when cooled, becomes citron-yellow.

11. *Tin*, when heated on charcoal, forms a white coating, which settles close around the assay, and reduces to metallic globules when treated with the reducing flame. With cobalt solution this coating becomes bluish-green.

12. *Lead* forms a yellow coating on charcoal, which in the reducing flame changes its place with the exhibition of a bluish light.

13. *Zinc* gives a yellow coating on coal, which upon cooling becomes white. When this coating is moistened with cobalt solution and heated in the oxidising flame, a yellowish green colour is produced.

14. *Nickel.* In the oxidising flame and upon platinum wire, with borax, the compounds of this metal give a reddish brown bead; with salt of phosphorus, a yellow bead. The nickel reduces easily in the reduction flame, giving these beads a grey colour.

15. *Cobalt* gives, with borax and salt of phosphorus in the oxidising and reducing flames, a beautiful blue bead.

16. *Iron*. The compounds of this metal give, with borax, upon platinum wire and in the oxidising flame, while hot a reddish, when cold a yellow bead, which in the reducing flame becomes bottle-green.

17. *Quicksilver,* when in combination, if heated in a closed glass tube with oxalate of soda, a grey metallic sublimate collects in the upper portions of the glass.

18. *Manganese* gives, with borax, in the oxidising flame, an amethyst-red bead, which when heated in the reducing flame becomes colourless.

19. *Alumina,* when treated on charcoal, moistened with cobalt solution and brought to a glowing heat, becomes blue.

20. *Soda,* in any of its compounds, gives the blowpipe flame an intense yellow colour.

21. *Silver*. This metal is best sought for by melting the compound supposed to contain it—after roasting, when necessary—with test lead, and then bringing the globule produced, which will hold all the silver present, upon a layer of bone ash. By a continual oxidising flame the lead may be oxidised and driven into the ash, and the pure silver that remains behind, in the form of a bright grain, may be proven by its malleability beneath the hammer. This method of separating lead from silver is called *cupelling*.

22. *Gold*. To discover gold in combination with other metals, as copper, &c., the substance should be cupelled; the globule obtained will be recognised by its colour and malleability. When however silver is present in any quantity, the globule obtained will be white. In this case the silver may be dissolved out in nitric acid, and the gold will remain behind.

As has been observed in a previous section, the blow-pipe furnishes the most generally applicable means for a metallurgist to discover the nature of those substances with which he deals. Without other aids it is often sufficient to settle the mineralogical species to which his ores or their accompaniments may belong, and in all instances its use developes characteristics that aid essentially in classification.

Ores are often subjected to such fine mechanical division before they reach the hand of the metallurgist, that simple attention to their obscured physical properties will seldom lead to a trustworthy and definite conclusion regarding the interior nature of the minerals present. Crystallography must take a subordinate position in regard to its value for the determination of species, since even where stamping has not been resorted to, distinctly crystallised specimens of ores are far from abundant, and with some varieties entirely unknown.

All the natural compounds of copper that are likely to be met with by the metallurgist, and with the exception of several rare and doubtful species, and a few minerals that contain copper only as an occasional constituent, all that are recognised by mineralogists, will be found described in the following section.

CHAPTER IV.

THE ORES OF COPPER, AND THE MINERALS CONTAINING THAT METAL AS AN ESSENTIAL CONSTITUENT.

Copper uncombined.

Native Copper (Cu) generally occurs almost pure, massive, filiform, and arborescent; lustre metallic, and colour yellowish-red. Hardness 2·5 to 3. Specific gravity 8·8, ductile, malleable, streak shining, cleavage imperceptible, fracture rough; before the blow-pipe (B. B.), fuses readily. Nitric acid dissolves it, giving off at the same time red fumes, and with ammonia a deep blue solution is produced. Occurs frequently in Cornwall near Redruth and elsewhere; a mass of 122 pounds was obtained from Condorrow mine, Camborne. In Chili it is sometimes found containing 7 or 8 per cent. of silver. In the United States, near Lake Superior, it occurs abundantly, and a mass was discovered in the Minnesota mine which weighed 400 tons.

Copper in combination with Arsenic.

Domeykite ($3 Cu_2 + 2 As$), 71·7 per cent. of copper and 28 per cent. of arsenic; occurs reniform and botryoidal; hardness 3 to 3·5.; specific gravity 4·2; colour tin-white, sometimes bluish or dark, lustre metallic, streak shining. When heated in a closed glass tube it gives off water, and forms a sublimate of arsenous acid. B. B. fuses easily with an odour of arsenic to a yellowish mass, with soda and borax yields a globule of copper. This rare mineral is found in Chili and Cornwall.

Copper in combination with Selenium.

Selenide of Copper (Cu_2Se), 61·6 per cent. of copper. Occurs in thin dendritic crusts; soft, lustre metallic, colour silver-white. B. B. gives the odour of selenium and fuses to a grey bead; on coal, with soda, copper is obtained. Occurs in the Hartz mountains.

Eucairite ($[Cu_2\ Ag]\ Se$), 25·3 per cent. of copper, 43·1 per cent. of silver. This mineral is found massive or in black metallic films, lustre metallic, and colour light lead, streak shining. B. B. acts as selenide of copper; but by cupellation gives a globule of silver. This is a rare mineral, from Sweden.

Copper in combination with Sulphur.

Copper Glance, or Redruthite (Cu_2S), copper 79·8 per cent., sulphur 20·2 per cent. Occurs massive, compact, or granular. Hardness 2·5 to 3, specific gravity 5·5 to 5·8. Colour and streak dark lead-grey, surface often tarnished, fracture conchoidal. Heated in an open glass tube, gives a strong odour of sulphurous acid. B. B. on charcoal, melts easily to a globule, which boils and gives off sulphurous acid gas; powdered and treated with neutral oxalate of potash in the reducing flame gives metallic copper. When quite pure this mineral may be cut with a knife and melted in the flame of an ordinary candle: the sulphide of iron is often present in it as an impurity, and this interferes with the hardness and fusibility of the mineral. Cornwall affords splendid crystals in the form of a modified rhombic prism, and it occurs there in veins with other ores of copper. It is also found at Fassnetburn, in Haddingtonshire, in Ayrshire; and Fair Island, Scotland; in Connecticut, Nova Scotia, and Saxony.

Variegated Copper ore ($3\,Cu_2S+Fe_2S_3$), 55·7 per cent. copper, 16·4 per cent. iron, and 28·1 per cent. sulphur; crystallises occasionally monometric, granular, lustre metallic, hardness 3 to 4, gravity 4·4 to 5, colour copper-red to pinchbeck-brown, tarnished, streak greyish-black, fracture conchoidal and uneven, brittle. When heated in an open tube, it gives off sulphurous fumes, but forms no sublimate. B. B. on charcoal melts readily to a globule, which is magnetic and brittle, and has a grey fracture; well roasted it gives, with borax and salt of phosphorus, the re-action of iron and copper. This mineral occurs with other copper ores in Cornwall, particularly at Tincroft and Dolcoath mines, where it is called by the workmen "horseflesh ore." It is also found at Ross Island in Killarney, in Tuscany, and in Connecticut and Pennsylvania.

Indigo Copper (CuS), 66·5 per cent. of copper, 33·5 per cent. of sulphur; sometimes contains iron and lead as impurities; occurs massive, spheroidal, or as a coating, lustre resinous, cleavage complete, hardness 1·5 to 2, gravity 3·8, colour blue-black, streak lead-grey, thin leaves, flexible, crystallisation hexagonal. When heated in an open tube gives off sulphurous fumes, and by high heat a sublimate of sulphur. B. B. burns, after becoming red hot, with a blue flame, and yields upon reduction a button of metallic copper. Occurs occasionally in Saxony, and abundantly in Chili.

Tennantite ($[Cu_2S + FeS]^4\,AsS_3$), 40 to 50 per cent. of copper; lustre metallic, hardness 4, gravity 4·4, fracture uneven, cleavage imperfect, crystallises monometric. Heated in a closed glass tube generally decrepitates, and gives a sublimate of sulphur and arsenous acid. B. B. on coal, melts with effervescence and sulphurous fumes to a dark grey magnetic globule. After being well roasted, it gives with borax the reaction of iron and copper. This mineral occurs at a number of places in Cornwall, but particularly near St. Day and Redruth, in splendid crystals with other ores of copper; also in Norway and Algeria.

Enargite ($3\,Cu_2\,AsS_5$), 48·2 per cent. copper, 32·6 per cent. sulphur, and 19·1 per cent. arsenic; occurs massive and granular, lustre metallic, hardness 3, gravity 4·4, colour iron-black, streak black, brittle, crystallises trimetric. Heated in a close tube enargite gives, after decrepitating, a sublimate of sulphur and sulphide of arsenic, which is of a reddish yellow colour. B. B. on coal, gives fumes of arsenous acid, oxide of antimony, and oxide of zinc, and in the reduction flame, with borax, yields a globule of copper. Occurs in large masses, at a height of 15,000 feet, on the Cordilleras of Peru.

Grey Copper ($[Cu_2S, FeS, ZnS, AgS]^4\,[SbS_3\,AsS_3]$), contains 30 to 40 per cent. of copper, and in some instances as much as 10 per cent. of silver. Texture closely granular and compact, lustre metallic, crystallises monometric, hardness 3 to 4·5, specific gravity 4·5 to 5·1, colour steel-grey to iron-black, streak sometimes inclined to brown, but generally the same as the colour, in thin splinters the mineral is sometimes cherry red, fracture uneven, brittle. Heated in a closed glass tube melts sometimes with decrepitation, and gives with a very strong heat a dark red sublimate of the sulphide of antimony. When the ore contains quicksilver, as is sometimes the case, the sulphide of that metal is sublimed at a low red heat, and collects on the glass in the form of a dark ring. B. B. on charcoal melts easily to a bead, gives off much vapour, and covers the coal with the white oxide of antimony, and in some instances with the oxide of zinc and lead. After roasting and melting on coal with soda, metallic copper may be obtained. The silver that may be present is sought for by melting the roasted ore with lead and borax-glass, and cupelling. The Cornish mines near St. Austel afford excellent crystals of this species; also found in Freiberg in Saxony, Kremnitz in Hungary, and the mines of North Carolina.

Copper Pyrites ($Cu_2S + Fe_2S_3$), copper 34·6 per cent., iron 30·9 per cent., sulphur 34·9 per cent.; occurs massive or in dimetric crystals, lustre metallic, colour brass-yellow, hardness 3·5—4, specific gravity 4·1, often iridescent, streak greenish black, a little shining, opaque, fracture uneven, conchoidal. B. B. on charcoal, blackens, but becomes red on cooling; melts easily to a globule, which is black, rough, and magnetic. Powdered and roasted on coal until all the sulphur is driven off, affords, with borax and salt of phosphorus, the reactions of copper and iron; dissolves in nitric acid, forming a green solution, which a drop of ammonia changes to a deep blue. This is the principal ore at the mines in Cornwall: it is there associated with the oxide of tin, variegated copper, copper glance, grey copper, galena, and blende. The ore, when picked and ready for sale, rarely yields 12 per cent. of copper, generally but 7 or 8, and occasionally but 3 or 4. Its richness may often be judged by its colour; if a fine yellow hue and readily yielding to the hammer, it may be considered good, but if hard and pale yellow, it is poor from admixture with iron pyrites. Copper pyrites is readily distinguished from iron pyrites, which it somewhat resembles, by its inferior hardness; it may be cut with a knife, while iron pyrites strikes fire with steel. It differs from gold, for which it has been mistaken, by being brittle; hence it cannot be cut off in slices like that metal, and moreover gold is not attacked by nitric acid. This ore is common in Sweden, in the Hartz, in Tuscany, and in various parts of the United States, Canada, and Australia.

Copper Bismuth Glance ($Cu_2S + B_2S_3$), copper 18·9 per cent., generally in thin striated prisms, lustre bright metallic, colour greyish or tin-white. In the open tube melts, gives off sulphurous fumes, and forms a white sublimate of the sulphate of bismuth; with stronger heat the specimen boils, and surrounds itself with melted oxide of bismuth. B. B. fuses easily, with intumescence, and gives with soda a globule of copper. This is a rare mineral from the Black Forest.

Sulphide of Silver and Copper ($Cu_2S + AgS$), copper 31·1 per cent., silver 53·1 per cent.; massive and compact, lustre metallic, colour dark steel-grey, streak shining, fracture subconchoidal. Heated in the open tube this mineral gives off sulphurous fumes, but forms no sublimate. B. B. gives a copper and sometimes, by reason of impurities, an iron re-action; by cupellation a globule of silver may be obtained. Dissolves in nitric acid. The blue solution thus formed precipitates silver on an immersed copper plate. Occurs with iron pyrites in Siberia; also in Silesia, Chili, and Peru, and in the silver mines of Arizona.

Tin Pyrites ($Cu_2S\ [Sn_2S_3, Fe_2S_3]$), copper 29·7 per cent., tin 27·3 per cent., iron 13·1 per cent. This mineral occurs massive or in grains, its lustre is metallic, streak black, colour steel-grey to iron-black, and has sometimes a bluish tarnish, fracture uneven. When heated in an open tube it gives sulphurous fumes and a slight sublimate of the oxide of tin. B. B. on charcoal, sulphur is expelled, and afterwards a dark scoriaceous globule is obtained; the coal is coated with the oxide of tin. With soda gives a globule of impure copper. At Huel Rock, in the parish of St. Agnes, Cornwall, this species accompanies iron pyrites and blende; it is found in the granite of St. Michael's Mount, and in Saxony.

Antimonial Copper ($Cu_2S + Sb_2S_3$), with 24·8 per cent. of copper, crystallises in columnar prisms, lustre metallic, streak black, colour dark lead-grey, hardness 3, gravity 4·7. When heated in an open tube gives off sulphurous fumes and vapor of antimony, which condenses on the glass. B. B. on charcoal, decrepitates, fuses readily, and gives a sublimate of antimony; and after a strong heat, with soda, a globule of copper. Occurs in the Hartz.

Cuban ($CuS + Fe_2S_3$), 19 per cent. of copper; occurs crystallised in cubes or massive, colour between bronze and brass-yellow, streak dark brown, hardness 4, specific gravity 4. B. B. fuses readily, giving off sulphurous fumes, shows more iron, but otherwise re-acts as variegated copper. Is found among the ores at Barracanao in Cuba.

Bournonite ($3\ [Cu_2S, Pb]\ S + Sb_2S_3$), with 12·8 per cent. of copper, and 41·8 per cent. of lead; occurs massive, granular, or compact, crystallises trimetric, lustre metallic, hardness 2·5-3, gravity 5·8, colour and streak steel-grey or darker, brittle. In closed tube this species gives a dark red sublimate. B. B. on charcoal, fuses easily giving off fumes of sulphur and antimony; in strong heat the charcoal is covered with oxide of lead. In nitric acid dissolves, giving a blue solution. This mineral was first found at Edillion, near Redruth; it also occurs at Beeralston, in Devonshire, in Chili, in the Hartz, and in Saxony.

Aikinite ($3\ [Cu_2S\ PbS] + Bi_2S_3$), with 11 per cent. of copper; occurs in slender trimetric crystals, and massive, hardness 2, specific gravity 6·5, lustre metallic, colour blackish lead-grey or reddish, fracture uneven. When heated in an open tube gives a white vapour and a sulphurous odour. B.B. on coal, melts easily, forming a yellowish white sublimate, and with soda reduces to a metallic bead. Occurs in Siberia, and in the United States at the Lubec mine in Maine.

Cuproplumbite (Cu_2S, PbS), copper 19·9 per cent., lead 65 per cent.; occurs massive or granular, or in cleavable grains; lustre, metallic; hardness, 2·5; specific gravity, 6·4; colour, dark lead-grey; streak, black; crystallises monometric. When heated in the open tube, fuses and gives off sulphurous fumes. B. B. on charcoal, gives a coating of the oxide of lead, affords a metallic globule which, when melted with borax-glass, gives copper.

Combinations of Copper with Chlorine.

Atacamite ($Cu\,Cl + 3\ [CuO + HO]$), giving 59·4 per cent. of copper; occurs in plates, massive, or in trimetric crystals; lustre, adamantine; hardness, 3 to

3·5; specific gravity, 4·3; colour, various shades of bright green, sometimes dark green; streak, apple-green, translucent. B. B. tinges the outer flame, when heated alone, blue, and gives off fumes of hydrochloric acid. On charcoal the copper is readily reduced to a metallic state. Occurs in various parts of Chili, in South Australia, and in Saxony. It is ground to a powder, and sold in Chili under the name of Arsenillo, as sand for drying letters.

Combination of Copper with Oxygen.

Red Copper [Cu_2O], with 88·8 per cent. of copper, occurs massive or granular, and in beautiful monometric crystals, sometimes earthy; lustre, adamantine, submetallic; hardness, 3·5 to 4; gravity, 6; colour, red, of various shades, occasionally crimson by transmitted light; streak, brownish red and shining; fracture, conchoidal and uneven. B. B. on charcoal, in the reducing flame gives a globule of copper; dissolves with effervescence in nitric acid. Occurs finely crystallised at Huel Gorland and other Cornish mines, in Tuscany and New Jersey, and the Lake Superior region, and abundantly in South Australia.

Black Oxide of Copper [CuO], 79·8 per cent. of copper; generally occurs massive or earthy; hardness, 3; specific gravity, 2·5; lustre, dull; colour, dark steel-grey or black; streak, shining. B. B. yields readily in the reducing flame a globule of copper. At Copper Harbour, on Lake Superior, 40,000 lbs. of this ore was removed from a vein in the conglomerate. It is also found in the Hartz, and in Saxony, and is abundant at the Burra Burra mine in South Australia.

Crednerite ($3\ CuO + 2\ Mn_2O_3$), 37 per cent. of copper, occurs in leaves, and possesses a perfect cleavage; lustre, metallic; hardness, 4·5; specific gravity, 5; colour, dark steel-grey; streak, black or brown. B. B. fuses with difficulty on the edges; with borax, gives a dull violet, and with salt of phosphorus a green glass. In hydrochloric acid dissolves, giving off fumes of chlorine, to a green solution. Occurs in the Thuringian forest.

Copper in combination with Acids.

Sulphate of Copper ($CuO, SO_3 + 5\ HO$), with 25·3 per cent. of copper, occurs amorphous or in triclinic crystals; lustre, glassy; hardness, 2·5; gravity, 2·2; colour, Berlin blue to sky blue; streak, uncoloured, translucent; taste, metallic; somewhat brittle. In closed tube swells, gives off water, and becomes white; mixed with powdered coal, gives sulphurous acid fumes. B. B. on charcoal and with soda gives metallic copper. This mineral is found dissolved in water which issues from mines, and in connection with rocks containing copper pyrites. It is produced in large quantities in Wicklow and Anglesea, also in Spain and Tennessee.

Brochantite ($CuO, SO_3 + 3\ CuO, HO$), with 56 per cent. of copper, massive, or columnar; hardness, 3·5; specific gravity, 3·8; lustre, vitreous; colour, dark green; streak, pale green, translucent. B. B. reduces with effervescence to a copper globule, which on cooling becomes black. Occurs near Roughten Gill in Cumberland and in Mexico.

Linarite ($PbO, SO_3 + CuO, HO$), with 15·7 per cent. of copper, is found in the form of monoclinic crystals, sometimes an inch long; lustre, vitreous; hardness, 2·5; specific gravity, 5·4; colour, deep azure blue; streak, pale blue, translucent. In closed tube gives off water, and loses its colour. B. B. reduces, and with strong heat gives a sublimate of oxide of lead. Occurs at Roughten Gill and Leadhills.

Connellite, probably a compound of the sulphate and the chloride of copper, crystallises in hexagonal prisms, with truncated edges; lustre, vitreous; colour, fine blue, translucent; occurs associated with arsenate of copper in Cornwall.

Phosphochalcite ($[CuO]^6, PO_5 + 3\ HO$), 56·4 per ent. of copper, occurs massive or indistinctly fibrous or crystallised trimetric; hardness, 4·5; specific gravity, 4·4; lustre, adamantine; colour, dark emerald green; streak green; fracture uneven. In closed tube gives off water, and becomes black. B. B. on coal melts to a dark vesicular globule, which contains a kernel of metallic copper. With borax or salt of phosphorus, gives the reaction of copper. Occurs at Virneberg on the Rhine, and in North Carolina.

Phosphate of Copper ($[CuO]^4, PO_5 + HO$), with 52 per cent. of copper, globular and compact; crystals, trimetric; lustre, resinous; hardness, 4; specific gravity, 3·7; colour, olive green, translucent; fracture, uneven. B. B. acts as phosphochalcite. Occurs in small quantities near Gunnislake Cornwall, and in Bolivia and Chili.

Chalcolite ($[CuO]^2, PO_5 + [U_2O_3]^4, PO_5 + 16\ HO$), crystallises dimetric; cleavage, perfect; lustre, adamantine and pearly, translucent; colour, green; hardness, 2; specific gravity, 3·5; streak, green. B. B. fuses to a black mass, colouring the flame bluish green, gives with borax a green glass, which becomes reddish brown in the reduction flame; in nitric acid forms a yellowish green solution. Found at Gunnis lake, Tin Croft, Huel Buller, and elsewhere in Cornwall; also in Saxony and Belgium.

Malachite ($2\,CuO + CO_2 + HO$) contains 57·3 per cent. of copper; usually occurs in globular forms, massive or incrusting; structure, radiating; crystals monoclinic; fibrous varieties, silky; colour, bright green; hardness, 3·5 to 4; gravity, 3·7; streak, pale green, translucent to opaque; fracture, uneven. In glass tube yields water of a dark colour. B. B. on coal fuses and affords a globule of copper; with borax gives a green glass. Dissolves with effervescence in acids, and also in ammonia. Occurs in Cornwall and Cumberland, at Chessy in France, in the Ural Mountains in large masses, abundantly in South Australia, and in various parts of the United States.

Azurite ($2\,CuO, CO_2 + CuO, HO$), with 55·1 per cent. of copper; massive, dull, and earthy; lustre, vitreous; crystals, monoclinic; hardness, 3·5 to 4; gravity, 3·6; colour, various shades of azure blue; streak, light blue, translucent; fracture, conchoidal. B. B. acts as Malachite. Occurs at Wheal Buller, and at other places in Cornwall, at Chessy near Lyons in small quantities, at Alston Moor and in Pennsylvania.

Aurichalcite, a carbonate of the oxides of copper and zinc, with 23·2 per cent. copper. Occurs in acicular crystals, forming incrustations, also granular; hardness, 2; lustre, pearly; colour, green, translucent. In closed tube gives off water, and becomes black. B. B. with soda and borax on coal, gives a coating of the oxide of zinc, and reduces to a globule of metallic copper. Occurs at Matlock in Derbyshire, at Roughten Gill, and also in Hungary.

Aphanesite ($[CuO]^6$, $AsO_5 + 3\ HO$), with 50 per cent. of copper, and 30 per cent. arsenic acid, occurs massive or radiated with perfect cleavage; crystals, monoclinic; lustre, pearly; colour, dark verdigris green, to blue, translucent. B. B. deflagrates, melts easily, gives fumes of arsenic, and reduces to a metallic globule. Occurs in Cornwall with other salts of copper, and also in Saxony.

Olivenite ($[CuO]^4$, $[AsO_5, PO_5] + HO$), with 45·2 of copper, occurs in fibres, plates, or granular; when crystalline, trimetric; lustre, adamantine, sometimes pearly; hardness, 3; specific gravity, 4·2; colour, olive to dark green, also wood brown; translucent to opaque; brittle. B. B. in the forceps colours the flame greenish, and melts to a bead, which is brown and crystalline on cooling. On coal fuses, giving off arsenical fumes, to a brittle metallic globule, which on cooling becomes covered with red scoriæ. Crystals of this mineral occur on quartz at the Cornish mines, also at Alston Moor, in Chili, and other places.

Euchroite ($[CuO]^4$, $AsO_5 + 7\ HO$), crystallises trimetric, with striated faces; lustre, vitreous; colour, emerald green; hardness, 3·5; specific gravity, 3·3; translucent fracture, uneven. In closed tube gives off water, and melts to a dark green mass. On coal melts with detonation, and reduces to a globule of malleable copper. This is a rare mineral found in Hungary.

Copper Froth; Oxide of copper, 43·8 per cent., arsenic acid, 25·4 per cent., occurs usually foliated, globular, or massive; hardness, 1—2; gravity, 3; lustre, pearly; colour, greenish blue, translucent. In closed tube gives off water, decrepitates, and grows dark. On coal, melts, giving off arsenious vapours, and reducing, with soda, to a metallic globule. Dissolves in acids. Is found in Hungary, Saxony, and Siberia.

Erinite, ($[CuO]^5$, AsO_5 + 2 HO), 59·9 per cent. of the oxide of copper, 37·4 per cent. arsenic acid. In concentric crystalline groups, fibrous and rough, traces of cleavage; hardness, 4·5; specific gravity, 4; lustre, resinous; colour, green; streak, green, translucent. Decrepitates when heated in a glass tube. On charcoal, reduces, giving off an odour of arsenic, and at length a malleable globule of copper is formed. Erinite occurs associated with other arsenates in County Limerick, Ireland.

Liroconite, 35 per cent. oxide of copper, with arsenic, phosphoric acid and water, crystalline form, trimetric, rarely granular; lustre, vitreous; hardness, 2; specific gravity, 2·8; colour and streak, greenish blue. When heated in a closed tube, loses water and becomes olive green. B. B. on charcoal melts with the development of arsenical vapours to a slag. Dissolves in nitric acid without effervescence; occurs, with various ores of copper pyrites, and quartz, at Huel Gorland and Huel Unity, in Cornwall, also in Hungary.

Chromate of Lead and Copper, (3 [CuO PbO] + 2 $Cr\ O_3$), containing 8·6 per cent. of copper. Is found granular and amorphous, lustre adamantine, crystalline form, monoclinic, colour, dark green to black, nearly opaque; streak, greenish. B. B. on coal swells, melts with effervescence to a dark green globule with specks of lead. With borax, in oxidising flame, gives a dark green glass, which in the reducing flame is red. This mineral is found in Siberia, France, and New York.

Vanadate of Copper, ($[CuO, CaO]^4, VO_3 + HO$), with 48·5 per cent. of copper, occurs finely crystallised, in a hexagonal form, also globular or as a coating; lustre fatty; hardness, 3 to 3·5; specific gravity, 3·5; colour, dark green or grey; streak, yellowish green, translucent. In a closed glass tube, when heated, gives off water and becomes black. B. B. on coal melts easily to a slag which holds particles of metallic copper. With salt of phosphorus on platinum wire, gives a pearl which is yellow in oxidising flame and green in reducing flame. Occurs in the Thuringian forest and in the Lake Superior region.

Emerald Copper, ($3\ CuO + 2\ SiO_3 + 3\ HO$) with 39·9 per cent. of copper, crystallises rhombohedral, with perfect cleavage; hardness, 5; specific gravity, 3·3; lustre, vitreous; streak, green; colour, emerald green, translucent; fracture, conchoidal. B. B. decrepitates, tinging the flame yellowish green, and in the outer flame becomes black, in inner flame red, but does not melt; fuses, with borax, to a green globule, and is finally reduced to metallic copper. Insoluble in nitric acid, but soluble in hydrochloric acid. This beautiful mineral is found in Siberia and in Nassau.

Chrysocolla ($3\ CuO + 2\ SiO_3 + 6\ HO$) with 35·7 per cent. of copper. Globular and massive, occurring as a crust; lustre, vitreous or earthy; hardness, 2—3; specific gravity, 2·1; colour, green, passing into blue,—often brown; streak, white, translucent or opaque. B. B. acts as Emerald Copper. Found, accompanying other ores of copper, in Cornwall, also in Saxony, Nova Scotia, Chili, South Australia, and Lake Superior.

CHAPTER V.

THE GEOLOGY, MINING AND MECHANICAL PREPARATION OF THE ORES OF COPPER.

WITH the exception of iron, the ores of no metal used extensively in the arts are more generally distributed than those of copper. Scarcely a political division exists upon the earth's surface where they do not occur in workable quantities. A glance at the Chapter devoted to statistics will show that, although England, Chili, Cuba, and the Lake Superior region of North America at present furnish most of the copper in commerce, the entire production is by no means engrossed by these countries, as Spain, Austria, California, and Peru may be said to engross the quicksilver production, or as Cornwall, and Devon, and the East Indies almost do with tin.

Nor is the old theory that sought to establish a relation between the occurrence of certain metals and the position of the various zones of temperature,—thus placing copper, with iron, near the poles, and gold and silver in the equatorial regions,—found to rest upon a general knowledge of facts. Copper veins pierce the formations that lie between the tropics as abundantly as those that are cut by the polar circles. It was one of the metals mined in the dominions of the Incas, whose possessions extended across the equator, and the ancient Indian term for the Andes is said to signify "copper mountains," while in Norway the ores of the cosmopolitan metal are wrought in the frigid region around the North Cape.

Nor is its occurrence confined to any particular geological group. Each of the chief members of the strata which compose the solid earth-crust, at least as far up as the chalk, have been found penetrated, more or less abundantly by its lodes, and it is probable that, under certain circumstances, its deposition may still be going forward.

The following table will furnish a rapid view of the ages, as nearly as have been determined, of some of the most important copper deposits of the earth, and at the same time will be found useful in giving the established succession of British formations. Although it will be observed that in geological chronology no exclusive "age of copper" can be pointed out, yet about the time of the deposition of the Permian and Trias formations, the introduction of that metal among the rocks, appears to have been much more extensive than during other periods. This age is represented in England by the Cornish deposits; in Germany by the *Kupferschiefer*, and in America by what has been denominated by some geologists, "the copper trap."

	Names of Groups.	Locality of Copper deposit.
	Recent.	In rounded masses on the shores of Lake Superior.
	Tertiary.	
SECONDARY.	Chalk.	In Algiers near the Mouzia pass. In Chili.
	Wealden and Oolite.	The Banat in Austria.
	Lias.	Département de l'Aveyron.
	Trias.	Chessy in France. The deposits of Lake Superior, Connecticut, New Jersey, and Pennsylvania, according to some authors.
PRIMARY.	Permian.	Western flanks of the Ural mountains, Mansfeld in Prussia, in Hesse, in Thuringia. The copper lodes of Cornwall though occurring in a much older rock.
	Carboniferous.	
	Devonian.	The lodes of Wexford, Ireland, at the close of this or beginning of following group.
	Silurian.	Eastern flank of the Ural mountains.
	Metamorphic.	Alten, Norway, and most of the deposits of Norway and Sweden. In the Alps, Colcabamha, Chili, and in Peru.

THE FORMATION OF VEINS.

Many circumstances connected with the occurrence of the ores of copper and other metals, are best explained by a reference to the theory which has been devised after long observation, to explain the manner in which veins are formed.

The solid surface of the earth by an unequal cooling of its different parts; by the dissolving out and consequent sinking of limited portions; or by means of the vibrations caused by earthquakes, has been rent by narrow clefts or fissures whose length and depth are indefinite, but whose width seldom exceeds a few fathoms, and is generally only a few feet. These clefts extending deep into the earth and forming unobstructed openings between strata of different inclination or nature, naturally became passages for the circulation of water. This fluid at a high temperature, and under the great pressure of the superincumbent mass, and while holding in solution carbonic acid and other chemically active substances, is known to be a solvent, in one or another form, of all the elements found in veins.

Now water after filtering through several thousand feet of a rock holding even a very minute quantity of a soluble metallic compound, would become gradually to a certain extent saturated with it, and then flowing into a cleft where a circulation of currents was going forward, would, upon receiving a new temperature, or rising to a zone of lower pressure, or coming in contact with some new chemical compound, deposit the metallic substance upon the walls of the cavity within which the change happened to take place. This process going on for a long series of years would at length fill the crevice, and a mineral vein would be formed. That lodes are sometimes otherwise produced—as, for instance, by the condensation of vapours issuing from a heated mass below, or by segregation from the surrounding rock—there can be no doubt, but these are exceptions to the general rule of formation.

Mineral veins rarely occur singly The discovery of one in any district may be considered a good evidence that others exist in the vicinity, for a convulsion so general as an earthquake would naturally produce numerous fissures, and their filling would go on simultaneously. But not only do veins form contemporaneous systems, but these systems are, as a rule, similar throughout in the general character of their ores, and are composed of veins having a direction nearly parallel to each other. Further, it is found, that frequently a vein, or a system of contemporaneous veins after having been completely formed, has been rent by clefts running in another direction; and that these subsequently became filled with substances differing in nature from those filling the first veins. This second system may be intersected by a third and of course younger formation, and so successively forward, the fact of cutting or being cut deciding the relative age of the vein or the system.

Observations made at the place of intersection of various veins or lodes have often enabled geologists to fix the age of mineral deposits to be very different from that which at first sight would seem to be the case. Thus, although many of the Cornish lodes are in granite, they have been proven to be the production of a period far more recent than the formation of that rock; and by the following ingenious course of reasoning, for which we are indebted to Sir Charles Lyell, have been shown to be vastly younger than the copper-bearing lodes of Wexford in Ireland.

In Cornwall the granite was first formed, then about the same period the veins of fine-grained granite, often tortuous, *penetrating* both the outer crust of the granite and the adjoining fossiliferous or primary rocks including the coal measures; thirdly, elvans, holding their course straight through granite, granitic veins, and fossiliferous slates; fourthly, veins of tin also containing copper, the first of the eight systems of veins which have been traced in Cornwall. Here then, since the second system mentioned is already younger than the coal measures, the fourth system must belong to a still later epoch; and although the exact age of the lodes is difficult to determine, it is quite clearly established that they are not newer than the beginning of the Permian formation.

Now to turn to the Irish mining district. We have granite in Wexford traversed by granitic veins which veins also intrude themselves into the Silurian strata, the same Silurian rocks, as well as the veins having been denuded before the Devonian beds were superimposed. Next we find in the same country that elvans, or straight dikes of porphyritic granite, have cut through the granite and the veins above mentioned, but have not penetrated the Devonian rocks. Subsequent to these elvans, veins of copper and lead were produced, being of a date certainly later than the Silurian and older than the Devonian, for they do not enter the latter.

Thus not only are the ages of the two series of veins settled, but the remarkable conclusion arrived at that between the formation of the ores of Wexford and the ores of Cornwall intervened that immense period during which the old red sandstone and the coal measures were deposited.

By similar methods of reasoning, several of the conclusions given in the last column of the foregoing table have been arrived at.

Copper however is not always won from deposits such as have been described. It occasionally occurs disseminated in workable quantities through limited beds of sandstone or shale, generally in the Permian rocks, as, for instance, in Mansfield in Prussia, where its ores are scattered through a thin bituminous layer, known as the *Zechstein,* which has been traced for many miles. The peculiarity of these ores renders it expedient to adopt in their treatment a peculiar metallurgic process, which will be found described under its proper head.

It follows from the above general considerations regarding the formation of veins, that no comprehensive rule can be given for the discovery of metallic deposits. Especially is this the case where the explorer finds himself in a country geologically unknown, and where as yet no evidences of mineral wealth have been disclosed. Under such circumstances the discovery is often due to chance, and the knowledge of many of the important mining districts of the world may be traced within historic times to such a source: as for instance the placers of California, and the silver, copper, and lead region about Freiberg in Saxony.

But let a single vein be found, and the search for other veins assumes a more systematic character; though even here infallible rules suited for every district are impossible, and long experience accompanied by a sound judgment will lead to more valuable results than any course resting entirely upon theoretical deductions. Blindly trusting exclusively to the one or the other of these methods of searching for truth, has led to the formation of many so-called rules which are either local or false. A few however that are founded on both, are worthy of the attention of every explorer.

RULES FOR SEARCHING FOR METALLIC DEPOSITS.

1. Veins are found more abundantly in the older crystalline rocks, than in the newer stratified formations.

2. Veins are more abundant in mountainous and hilly regions than in the even land.

3. Metallic deposits are more abundant and richer in the vicinity of eruptive rocks, such as elvans or granitic veins, than at a distance from them.

4. Veins may frequently be discovered by observing the peculiar form or colour which is displayed by the surface of the land; thus, in the copper region of Lake Superior, the miners are guided in their search for the veins of native metal by the narrow valleys which, in consequence of the friable nature of the vein-stone, have been scooped out by the action of water, above the valuable mineral. Circumstances of an opposite character exist in Algeria, where a lode containing gray copper accompanied by a refractory vein-stone of heavy spar and spathic iron, traverses a soft marly formation. The easily decomposed enclosing rock has been carried

away by atmospheric agencies, and the veins remain like walls above the surface.

In uncultivated regions the fragments of the vein are often found scattered upon the surface, or colouring the soil by their decomposition.

5. Springs issuing from the neighbourhood of metallic deposits often hold salts in solution, indicating the presence of certain ores.

6. The action of water in washing away the clay and soil that hide the solid rock in which lodes occur, is of essential service to the explorer, and in many instances veins have been discovered by tracing the fragments of ore and vein-stone found in the bed of torrents back to the source from which the current had dislodged them.

The method of searching for mineral deposits as practised by the Cornish miners, is called *shoding* or *costeaning*, and is applicable where the general direction of the veins is already known, or where the position of the vein to be sought is nearly ascertained. It is carried out by sinking a number of *shode pits* each about 3 feet in width, 6 feet in length, and having a depth sufficient to pierce the alluvial deposits and enter the subjacent rocks, in a line at right angles to the supposed direction of the lode. To avoid missing any trace of ore which may exist between these pits, they are joined at their lowest points by galleries cut through the rock, which give an opportunity for a more complete exploration. When the direction of the vein is not approximately known, this line of pits is crossed at right angles by a second line, and a second gallery is driven, by which means, if any vein occur, it cannot fail to be detected.

The upper portions of many copper lodes, and especially those of Cornwall, consist of quartz, more or less full of cavities, and largely mixed with earthy brown iron-ore. This is called *gossan*, and its discovery is hailed as the precursor of wealth below, and where the black oxide of copper is plentiful among the ferruginous matter, the abundance of copper-ores further from the surface may be confidently expected.

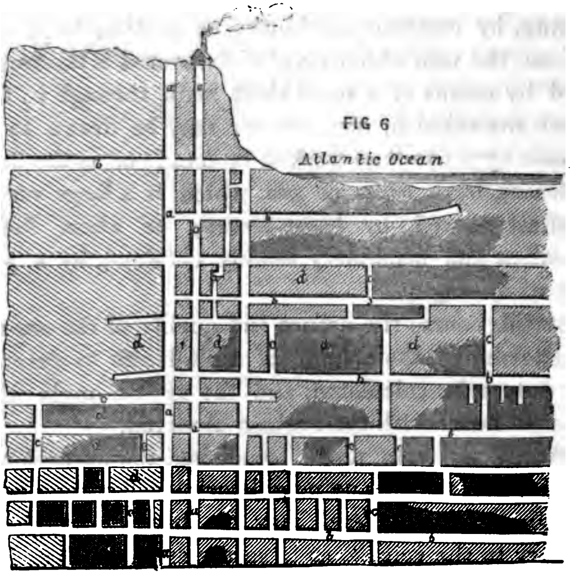
Before entering upon extensive preparations for mining, by erecting machinery or making large excavations, the vein which may be discovered is thoroughly tried by means of a small shaft sunk through it, from which the rubbish, ore or water may be drawn to the surface by a windlass worked by hand; or as the depth increases, by a *whim* or *gin*, which is a large vertical windlass moved by horse-power; or where fuel is abundant and machinery readily obtained, by a portable steam-engine.

By this course the nature and quality of the ore may be determined, the amount of capital safe to devote to the enterprise calculated, and the *dip* or angle which the vein forms with the horizon observed.

Should the vein prove promising, the miners' next care is to fix upon some neighbouring valley from which a gallery or *adit level* may be driven through the country to the vein, so as to secure drainage at as low a point as possible; a large shaft is sunk at a proper point, and supplied with the machinery necessary for drawing up the ores and pumping out the water.

The accompanying cut of the Levant Mine, St. Just, which the daring Cornish miner has extended far beneath the bed of the ocean, and whose steam-engine, perched on the cliff high above the surf, forms a striking feature in the bold coast scene, will serve to render more clear the conception that every metallurgist should possess, of the circumstances attending the winning of those ores, the smelting of which is the immediate object of his care. It represents a section taken on a plane passing through the middle of the lode.

The *shafts a a*, pierce the earth perpendicularly; at their mouths is placed the proper machinery for pumping the water and raising the ore that may be mined below. The galleries or *levels b b b*, are driven through the lode nearly in a horizontal direction, and generally at a distance of 10 fathoms from each other. These are large enough for the convenient passage of small wagons, or other contrivances for transporting the ore to the bottom of the shaft. When not surrounded by



firm rock, they are made secure by erecting around them a strong wooden framework, known as *timbering*, which resists the outward pressure, and prevents the sides and roofs from caving in. These levels are joined by *winzes c c c*, which serve as means of communication between different parts of the mine, and furnish channels for the circulation of fresh air, which must be carried to every part of the works where men are employed. After the levels are driven, the ore is taken out of the space represented by the parallelograms *d d d* by the operation known as *stoping*, and the opening thus formed is filled with the rubbish of the mine. The darkly shaded parts in the cut indicate the portions of the lode which have been *stoped*, while the lightly shaded spaces designate the portions yet undisturbed.

MANNER OF EXTRACTING THE ORE FROM THE VEIN.

Most ores are so firm in their texture as to require the employment of considerable force to loosen and reduce them to fragments of a convenient size for carrying to the surface. The method which is adopted depends on the physical properties of the rock, and the circumstances that surround the mine. In Cornwall, if the ground be passably soft, the ordinary pick and shovel are found sufficient: if it be stratified, or filled with fissures, the miner has recourse to steel wedges or points called *gads*, by driving which into the rock, he is enabled to split off pieces of considerable size. Another and a far more potent aid in excavating is found in gunpowder, which was first introduced into the mines of Cornwall about the beginning of the 18th century. By means of a steel chisel or *borer*, a hole is drilled a foot or more into the solid rock; at the bottom of this hole a sufficient quantity of blasting powder is placed, and a mass of soft schist—called *tamping*—is rammed very solidly into the remainder of the hole, care being taken to retain a communication with the powder by means of a sort of slow match, known as "patent safety fuse," or by a piece of wire which is subsequently pulled out, and fine powder poured into the slender hole that it leaves. By means of one of these expedients, the workman is enabled to convey fire to, and explode the powder within the rock, and a mass is thus torn away which is greater or less according to the depth and direction of the hole, the amount of powder and the nature of the rock. The mass thus dislodged is broken with hammers into small fragments, and the valuable portions picked out and sent to the surface.

A method of attacking the rock that was well known to the ancients, and that enabled them even with imperfect tools of copper or bronze to penetrate the most refractory deposits, consists in exposing the rock to be excavated to the heat of a strong fire, until it reaches a high temperature, and then allowing it to cool. Unequal expansion, the action of vapours formed in the crevices, and to some extent changes of a chemical nature, leave the exterior portions of the rock thus treated softened and full of cracks, so that it can be readily removed. This method, although still in use in a few mines where fuel can be obtained at a very low rate, as in some parts of Sweden and Norway and the Hartz, has been generally displaced by the introduction of gunpowder, and has now chiefly a historical interest.

In extracting the native copper from the huge veins of the Lake Superior region, a formidable obstacle is experienced on account of the vastness and solidity of the masses in which the metal occurs. A hundred tons are not unfrequently found in a single piece, which of course before it can be drawn up, transported to the shore and shipped, must be divided into manageable blocks; these are now much larger than formerly, and sometimes reach the weight of 8000 or 9000 lbs. The usual plan adopted is to dislodge the mass from the wall by heavy charges of powder, but this agent is inadequate for accomplishing a further division, since the tamping, however excellent, is blown from the hole in the same manner that a ball is driven from a cannon. Long slender steel chisels having a cutting edge about a quarter of an inch in length are managed by two men; one to direct the tool while the other strikes with a heavy hammer; by this means narrow channels are cut, chip after chip, through the mass. The process, which requires much skill, is at best exceedingly slow, thirty months of constant work having been required to cut up a single mass.

The ore of most mines, when broken from its resting-place in the earth and brought to the surface, consists of two portions, viz., valuable metal chemically combined with some mineraliser, as sulphur; and worthless vein-stone or gangue that is mechanically mixed with the rich portions, and which generally composes by far the greater part of the mass raised. To separate this worthless gangue as completely as possible, and thus concentrate the valuable metalliferous portions to a sufficiently high per centage of metal to make the further concentration and purification by fire profitable, a series of mechanical processes are in use, differing in various countries and with various ores.

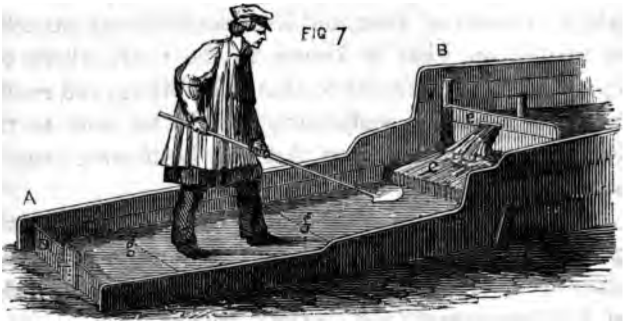
In Cornwall the mineral upon arriving at the surface is thrown into the proper places appointed to receive the various portions raised from the different parts of the mine; they are then broken or *spalled,* and divided into pieces of good ore, commonly called *prills, dredge ore,* and *halvans* or *leavings.* The best ore requires no further preparation, but may at once be stored ready for sale; the poorer, must undergo a process of powdering, which is generally performed by machinery driven by water or steam. Two large cylinders or rollers of steel or cast-iron are placed close to each other, and so geared together that they move in opposite directions. These rollers are turned round forcibly, and the fragments of ore, placed in a hopper above, are allowed to fall gradually between them and are thus crushed to a coarse powder; this powder then falls into the interior of a long cylindrical sieve of wire-gauze, which is turned slowly by the same power that moves the rollers. The fragments are thus divided into two classes, that which passes through the meshes and falls on the floor, and that which being larger than the openings, is carried to the lower end where, falling into the buckets of an endless chain, it is elevated to the rollers to be re-crushed.

Instead of this apparatus for breaking ores a stamping-mill is sometimes employed, especially where the ores are finely disseminated through the quartz or other hard matters of the lode. The stamping-mills are driven by water or steam, and consist of a number of upright beams of wood or iron, having heads of iron weighing 300 to 400 pounds at the lower end. These are placed side by side in a long trough, the bottom of which is of iron, and having to act the part of an anvil, is built on a deep and solid foundation. These stamps are capable of a vertical motion of about a foot, and when in motion, are alternately acted upon by a horizontal axle connected with the power and furnished with cams that, coming in contact with ears on the shanks, raise them slowly and allow them to fall suddenly on whatever may be beneath. The ore to be powdered is thrown into this trough, and coming under the heavy hammers is soon finely divided, and may be carried away by a small stream of water that is kept continually flowing from one end of the trough to the other.

The ore is now ready to be subjected to a process of concentration, depending on the different specific gravity of the valuable and worthless particles of the powder. As a general rule, the metalliferous parts that it is desirable to collect are much heavier than those that originate in the poor and earthy vein-stone. Thus by a reference to the chapter on Copper Ores, it will be found that copper pyrites is 4½, and the sulphide of copper 5½ times heavier than water; while quartz is but 2½, and chlorite but about 3 times heavier than the same fluid. Hence it is easy to see how when a powder consisting of a mixture of these substances, is allowed to fall through water, the metalliferous particles will reach the bottom first, and there form a distinct layer upon which the earthy particles will subsequently fall, or how, when such a powder is suspended in running water, the lighter particles will be carried much further than the heavier, and may thus be separated.

The first of these principles is taken advantage of in the old method of washing ore by the *hand-sieve.* This is a sieve of convenient size, having a bottom formed of a perforated sheet of copper. The workman partly fills it with crushed ore, and holding it in a large tub of water gives it a sort of undulatory motion which causes the water to enter at the bottom, and partly suspending the particles to be divided causes them to arrange themselves according to their specific gravities. The fragments lying on the top are considered worthless, and are scraped off and thrown away; the next layer is put aside for further washing, while the bottom stratum is deemed sufficiently rich for metallurgic treatment. An apparatus requiring much less manual labour is now often used. It consists of a large box covered with a tight wooden floor, in the centre of which is a circular metallic trough perforated with six holes, each about two feet in diameter, and into all these openings a sieve is closely fitted. A large piston working in a cylinder placed in the centre of this arrangement, and which is moved by an excentric that is driven either by steam or water power, is made to alternately raise and depress the level of the water in the box, and consequently in the sieves which are fixed water-tight in the rings at the top of it. By this motion of the water the particles of the mineral contained in the sieves are made to arrange themselves according to their several densities, and when it becomes necessary to remove a sieve for the purpose of scraping off the lighter and less valuable portion of its contents, its place is supplied by another, which is kept ready filled to occupy the same ring when required. The contents of the sieve are then carefully divided, the lightest part thrown away, the poorer metalliferous portions sent again to the stamping-mill, and the rich layer at the bottom put aside for the smelter.

The separation of different qualities of ore by means of a stream of water, is generally adopted where the stamping-mill has brought the mineral to the form of a very fine powder. The apparatuses which have been contrived for accomplishing or assisting this separation in different mining regions, are numerous, and sometimes quite complicated.



The Nicking Buddle, often used in Cornwall, consists of a trough A B, furnished with an inclined head-board C, over which a current of water may be allowed to flow from the hole *e*, the size of which is regulated by a wooden plug. At the lower end of the trough the water passes away through the holes at D. The washing is performed by throwing powdered ore upon the head-board C, where it is stirred with a shovel until it is washed into the body of the trough; here the workman, standing in the buddle, continually sweeps with a broom the ore backward against the current which falls from the head-board. By this incessant stirring, the particles are made to arrange themselves more regularly, and the lighter portions are carried further in the direction of A. As the trough fills, the holes at D are one by one plugged, and when full, the water at *e* is shut off, and the contents, after draining, are divided into three classes, as shown by the lines *f* and *g*. That above *f* is the richest, and is frequently pure enough for the purposes of the smelter; the second portion between *f* and *g* is thrown aside to be again buddled; while the third and lowest portion, which consists of finer and less metalliferous particles, is treated on what is known as the *rack*, where the operation is very similar to that of buddling, and results like it in a portion sufficiently rich to be sent to the furnace, and a poorer part that may be thrown away or subjected to further washing.

The action of the Nicking Buddle explains the general principle upon which most apparatuses having a similar object, as the *German chest*, the *sleeping table*, and the *percussion table*, perform their work.

The Cornish copper ore having been brought to a condition suitable for smelting, it is announced for sale on a given day several weeks in advance of the time fixed. In the meantime the assayers of the smelting works, resident in Cornwall, and those of the sellers, take samples with great care from the different heaps, and determine by the method given in the chapter on Assaying the per centage of copper in each sample. A few days previous to the sale the assayers meet, and a list of the lots taken, with the produce of the seller's assay, is made out, and sent to the smelter accompanied with the assayer's private determination and remarks. Before the day of sale arrives, the price that will be paid for the ores is fixed, so that when the buyer and seller meet in Pool, Truro, or Redruth, the business necessary for transferring the possession of many thousand pounds worth of ore requires but a few minutes. The parties being present a neutral person is appointed to the chair. He begins by reading over the numbers and particulars of the lot to be sold, when each buyer writes on a slip of paper the price per ton he will give, and hands it to the chairman, who examines the amounts and declares the highest bidder, purchaser. This sale, from the manner of sending the bids in on paper tickets, is called a *ticketing,* and the custom seems to have been in existence nearly in its present form for about 130 years. Formerly a sum called the *standard* was much used for indicating at once the rise or fall in the price of the ore. It is the cost of one ton of copper as reckoned by adding the price of that amount of metal as paid for in the ore, to the sum of the cost of transportation, smelting and the necessary profits.

Napier gives the following rules for fixing the price in buying ores;—1st, Fix the price you determine the copper contained in the ore shall yield when delivered in the works: say for example you fix upon £65 per ton, and the ore to be bid for has $14\frac{1}{8}$ per cent. Multiply the percentage by the price and divide by 100.

$65 \times 14\frac{1}{8} = 918 \div 100 =$ 9*l.* 3*s.* 7*d.* per ton of ore.

But there are 21 hundredweight given to the ton, and other general allowances amounting to 7 per cent. to be added making 13*s.* 6*d.* + 9*l.* 3*s.* 7*d.* = 9*l.* 17*s.* 1*d.* 2nd, From this sum is now to be deducted the *returning charges,* which are the net costs that practice has shown are incurred in melting an ore, and this differs with different smelters, but for illustration we will keep by the rule. An ore of 9 per cent. produce, costs 22*s.* per ton smelting; 1*s.* per ton is added for every per cent. above, and 1*s.* deducted for every per cent. below 9 per cent. Thus 14⅛ per cent. will cost 27*s.* which deducted from 9*l.* 17*s.* 1*d.* leaves 8*l.* 10*s.* 1*d.* as the sum to be bid for the ore. A little more or less is given according to requirement.

The next care of the smelting companies is to transport their ore from the mines, to the various harbours of Cornwall and Devonshire, where it is generally taken on board as a return load by vessels that bring fuel from the Welsh coal beds to supply the steam engines and manufacturing establishments along the southern coast, and thus it is carried at a low rate of freight to the wharves of Swansea or the neighbourhood, whence it readily reaches the furnaces. The vast quantities of ore reaching Swansea from other parts of the world, are crushed, sampled in the same manner as is customary in Cornwall, and sold at ticketings that generally take place twice a month.

CHAPTER VI.

ON ASSAYING; OR THE VARIOUS METHODS OF ESTIMATING THE PERCENTAGE OF COPPER IN ORES OR OTHER CUPREOUS COMPOUNDS. THE ENGLISH METHOD. THE GERMAN METHOD. THE ASSAY WITH THE BLOWPIPE. THE HUMID ASSAY.

AT the commencement of all the metallurgic processes which we are to consider, stand the following questions:—

1st. What is the amount or percentage of copper contained in the ore or compound to be operated upon.

2nd. What is the nature, and what are the amounts of the substances with which the copper is combined.

Upon the replies received must depend the value of the ore or compound in regard to the amount of copper possible to obtain from it, as well as the character of the processes that must be adopted to obtain the pure metal.

Questions so important as these require the most careful consideration, and the office of the assayer, whose duty it is to answer them, is one of much responsibility.

The art of assaying developed the science of analytical chemistry; it is extremely ancient, and the methods in use vary widely in different parts of the globe. In copper assaying we may distinguish four different modes of operation—in the preliminary examination for all of which the use of the blowpipe, (see Chap. III.) is generally advisable.

I. *The English method.* By this method most of the ores of copper are assayed; in some of the laboratories of Cornwall it is employed to make from 8000 to 10,000 estimations in a single year. It is but an imitation, upon a small scale, of the Welsh method of smelting and refining copper, which will be found treated at length in a subsequent Chapter, and consequently by it the assayer obtains metal identical in quality with that which he may expect to be produced in the furnaces from similar ore. Hence he is enabled to determine, directly, the real value of the ore for the purpose of the smelter, for it is evident that this value is as well an element of the quality as of the quantity of the metal produced.

On account of its directness, the English method is to be preferred to all others, though, as regards the accuracy with which the total quantity of copper contained in the ore, is determined, it falls behind those which follow.

II. *The German method* recommends itself by its simplicity, and the close approximation which can be attained to the full percentage of copper in the sample.

III. *The assay with the blowpipe* has the advantage of considerable accuracy, and requires but little time and but small outlay for instruments; but to secure satisfactory results, more skill is necessary than for either of the foregoing methods.

IV. *The humid methods of assaying* have the advantage of cheapness, ease, rapidity of execution, and great accuracy, but for their proper management a moderate amount of scientific knowledge is essential. Several modifications are specially adapted for the determination of extremely small quantities of copper.

I.—THE ENGLISH METHOD OF ASSAYING.

For accomplishing this assay a wind furnace is used, such as is represented by the accompanying figure. The opening, *a*, in which the fuel and crucibles are placed, is 10″ long, 8″ wide, and 14″ deep to the grate bars, *g*. The opening, *b*, leading to the chimney, *c*, is 8″ long, and 2″ high. The top of the opening, *a*, should be furnished with a slide, which may be more or less drawn aside at the will of the assayer. The remaining portions of the furnace are sufficiently explained by the figure. Good coke is used as fuel, and the assays, of which six may be conducted at once, are placed in crucibles and set directly upon the glowing mass; no covers are used for these crucibles, and the course of experiment can be observed from above.

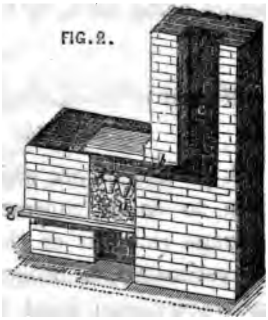


FIG. 8.

A balance is required which, with 450 grains in each pan, will turn perceptibly with the addition of $\frac{1}{20}$th of a grain.

The crucibles or smelting pots used are of three sizes, though but two of these are generally employed; the largest are about 4″ high, and have the shape shown in fig. 9; the smallest will just fit inside the largest. They are made extensively at Redruth, and are composed of a light coloured, coarse, and very refractory clay. The outfit of the assayer includes, in addition, various tongs of convenient shape for handling the crucible while hot, rods for stirring, mould plates for receiving the melted substance when poured from the crucible, a hammer and anvil for testing the malleability of the copper button, bronze or cast-iron mortars, and spoons or ladles of particular sizes for measuring fluxes.

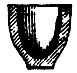


FIG. 9.

The fluxes and reagents required are,—common salt in its usual damp condition; common salt freed by heating from moisture; borax; powdered lime; powdered fluor spar; saltpetre; powdered charcoal; tartar; sulphur; and *white flux*, a mixture prepared in the laboratory, consisting of tartar 3 volumes, saltpetre 2 volumes, and a small quantity of common salt: these are mixed intimately in a mortar, and deflagrated before being used, by stirring with a hot iron rod.

Manner of conducting the assay of the ores of copper by the English method.

A portion of ore which has been selected with great care so as to represent, as nearly as possible, the average richness of the heap, the value of which is to be estimated, is brought, in a powdered state, to the laboratory, and dried by a heat that should not exceed 212° Fahr.

A small portion of this powder is then placed in a shallow, flat-bottomed copper basin, and washed by giving the vessel an oscillatory motion, and at the same time allowing the water and earthy impurities to flow away at one side. By this means the different metallic particles are made to arrange themselves in bands, according to their specific gravity, and a good judgment can be formed from their appearance, of the general nature of the ore. Such judgment may determine the assayer whether to submit it to the treatment of the "warm sample," or that of the "raw sample."

The "warm sample" embraces the ores that contain a considerable quantity of sulphur, and which must be subjected to a preliminary roasting. The "raw sample" includes such as require sulphur to be added to them, or which are sufficiently desulphurised to need no roasting. After the roasting of the minerals of the first sort, which is done in a common crucible, and requires from ten minutes to half an hour, both classes are subjected to the same general treatment; the different stages of which are as follows :—

1st. Fusion for *Regulus.*
2nd. Roasting the *Regulus.*
3rd. Fusion for *Crude copper.*
4th. One or two fusions with fluxes, called "*Washings.*"
5th. Testing with the hammer and *Refining.*
6th. Treatment of the slags for the copper they contain for "*Prill.*"

1st. *Fusion for Regulus.* 400 grains of the "raw sample," or the remainder of the same quantity of the "warm sample" after roasting, are placed in one of the large crucibles, and mixed with a ladle of each of the three fluxes, borax, fluor spar, and slacked lime, above which is added a layer of common salt. If the "raw sample" consists of a very poor pyrites, an additional ladle of saltpetre is given; if the ore is chiefly copper glance and other minerals containing little sulphur, ½ to 1 ladle of sulphur is added, so that enough of this substance may be present to form a good regulus. These latter additions are made after the crucible has been placed on the glowing coke, and maintained at a high heat for about 15 minutes. A few minutes later a little lime, fluor spar, and borax are thrown in, and at the end of about 20 minutes from the commencement, the assay is poured out into the cavity of a cast-iron mould plate. The button thus formed is taken from the iron plate and plunged into water, where it must be allowed to remain after it has cooled. This immersion enables the easy separation of the slag from the enclosed regulus.

In the above detailed process the object in adding borax is to form, with the quartz, oxide of iron, clay, magnesia, lime, and other earthy substances contained in the ore, the easily meltable boro-silicates which separate as slag. The fluor spar forms volatile fluoride of silicum, and silicate of lime. The oxides of copper, antimony, tin, &c., lose their oxygen, attract sulphur, and form a compound of sulphides which collect and compose the regulus.

This regulus should be bluish or bronze coloured, with much lustre, and containing from 40 to 70 per cent. of copper. If it is either very poor and dull, or very rich and bright, it should be rejected as being, in one case, too ferruginous, in the other as containing but a portion of the copper in the original ore. The regulus is powdered finely in an iron or bronze mortar, a little coke being added to prevent adhering to the sides of the vessel, and the powder poured carefully into one of the larger crucibles.

2nd. *Roasting the Regulus.* The pot containing the powdered assay is now placed on the fire. At first the heat should be moderate that the particles may not bake together, but toward the end of the operation the fire may be increased. The assay is stirred continually with a steel rod, and at the end of about half an hour it generally has assumed an earthy appearance, and no more sulphurous fumes are evolved. The process, which is simply that of driving off the sulphur, and forming oxides of the metals, is now considered concluded.

3rd. *Fusion for crude copper.* This takes place in the crucible which has been used for roasting, or one of the same size. The assay is mixed with ¼ ladle of saltpetre; ½ ladle borax; ⅛ ladle coal powder; 1 ladle of dry salt; and 2 ladles of tartar. Two ladles of common salt serve as a cover. At the end of ten minutes when a good fire is maintained, the mass is completely fluid, and then a little white flux is added. Soon afterwards the crucible is removed from the furnace; its contents poured by a single movement into a greased iron mould-plate, and the crucible returned to the fire. The object of this smelting is to obtain a *crude copper*, free from sulphur; the saltpetre serves to carry away the sulphur; the borax acts as a flux; the salt renders the mass easily fusible. The coal powder and tartar are very important re-agents, since by furnishing carbonic oxide they reduce the oxide of copper to a metallic state.

4th. *Fusion with fluxes, "Washing."* The *crude copper* button is now placed in the crucible together with one ladle of white flux and two ladles of dry salt. The white flux acts to oxidise the adulterating metals, and the salt to form volatile chlorides with the arsenic and antimony. After remaining four or five minutes in a fluid condition, the assay is poured out into a mould-plate; the button of copper examined, and if it appears very impure, it must be put through a similar process of washing a second time.

5th. *Testing with the hammer and refining.* The button cleaned of its slags is placed upon an anvil and tried with a small hammer; the presence of tin is indicated by its hardness, of antimony by its brittleness. It is then put alone into the crucible, subjected to a high heat, and when it shows what the assayers call the *eye*—that is, clear bright edges and a peculiarly dark variegated centre—the same fluxes used in washing are thrown in, and in a few minutes the fluid mass is poured as before into one of the mould-plates. In the midst of the slag is found the button of copper, possessing generally a clear red colour which is the proof of the success of the assay. If the fluxes last thrown in have been added too late, the button is found covered with a coating of the sub-oxide; if they were added too soon the button is dull from unreduced oxides. The process of refining is simply one of oxidation; those metals which have more attraction for oxygen than copper, as lead, iron, zinc, are acted upon by the air, changed into oxides, which separate themselves from the copper, causing the phenomenon of the *eye*. The ores of Cornwall on account of their peculiar composition generally require a longer time before the appearance of the *eye*, than those of foreign mines.

6th. *Treatment of the slags for the copper they contain.* All slags from the fusion for coarse copper and from the washings have been carefully preserved. They are melted with one ladle of tartar and some coal powder for about ¼ of an hour. The globule obtained is called "prill;" it is larger or smaller, as more or less metal has escaped into the slags. When necessary, it is subjected to purification, and is then added to the copper button produced in the 5th process, and both are weighed. This weight expressed in grains and divided by 4, gives directly the per centage of copper obtained from the ore.

If as is mentioned in the description of the 5th process, tin is detected by the hardness under the hammer, and by the brown colour of the button, the assayer will not be likely to obtain the *eye* satisfactorily in the next process of refining. In this case, that the tin may be eliminated as fully as possible, the button is submitted to one or more washings till the colour and malleability of good metal are reached.

The antimony which is also detected by the hammer, is best driven out by a careful roasting. If washing is resorted to a second time, a small addition of lead will assist the action.

The presence of zinc is very disadvantageous, it is perceived by the regulus having a brown colour resembling blende. A ladle of borax and half a ladle of saltpetre will carry it over into the slag.

Notwithstanding the apparent complexity of the English method of assaying, it is capable in experienced hands of being quite rapidly carried through, and the nature of its different stages allows the detection of the various adulterating metals with which the copper is combined. It gives invariably however too little metal, and to arrive at a figure representing the total amount of copper in the ore, it is necessary to add ½ to 2 per cent. to the results obtained.

That the test—although it may want in scientific accuracy—is adapted to the practical requirements of commerce, follows logically from the fact, that the loss in the assay indicates and to a certain extent measures the loss that must take place in the furnaces.

II.—THE GERMAN METHOD OF ASSAYING.

The process adopted for determining the amount of copper in mineral products at the various smelting establishments of Central Europe, differs considerably from the English method just described. It generally indicates a larger percentage of copper in the same ore, and it requires fewer manipulations.

In order to accomplish it, the following apparatus and fluxes are required.

A *muffle furnace,* having the construction shown in the accompanying figure 10. It is adapted for burning soft or bituminous coal, and is so arranged that the crucibles do not come in contact with the fuel or flames. It consists of a muffle *a* of refractory clay with small apertures at the sides and hinder end through which air may pass, and a larger aperture in front, *b,* that may be closed with a tile, and which furnishes an opening for introducing the assays. The muffle is heated by building a strong fire upon the grate *d,* the flames of which play through the open space surrounding *a,* and pass off by the chimney *c.* A commodious ash-hole is supplied by the space *e,* and at *f* is an iron door furnished with a slide *g,* by which the draught is regulated.

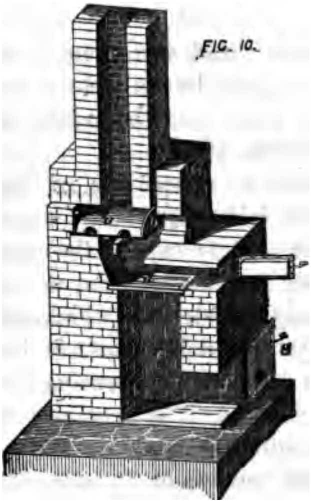


FIG. 10.

When coke, charcoal, or other flameless fuel is employed, this furnace is replaced by one so constructed that the muffle lies imbedded in the glowing mass.

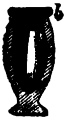


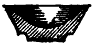
FIG. 11.

2. *Crucibles.* These are made of fire-clay, and are of an oval shape as represented in fig. 11. They are about 4½″ high and 1⅞″ interior

diameter. The bottom, which is broken off after the crucible has been used, serves for a cover for subsequent assays, in the manner shown at *b*.

3. *Roasting cups*, fig. 12, are also of fire-clay, 1⅛″ high and 2½″ in greatest diameter.

FIG. 12.



4. Tongs of iron for handling crucibles.

5. Besides the borax, salt, and powdered charcoal used in the English assay, powdered glass, metallic arsenic, lead, and graphite are employed, and a mixture known as "black flux" is used as a reducing agent. It consists of one part of saltpetre and two parts of crude tartar, which after being intimately mixed in a mortar are deflagrated by being heated in a crucible.

Manner of conducting the assay of the ores of copper by the German method.

We distinguish here but three operations.

1st. *Roasting*, or depriving the ore of sulphur and other volatile substances, and forming metallic oxides.

2nd. *Melting for crude copper.*

3rd. *Refining.*

1st. *Roasting*. About 60 grains (3·75 grammes) of the dry ore are carefully weighed, mixed with about 15 grains of graphite powder, and spread upon the bottom of the roasting-cup (fig. 12). This is introduced into the red-hot muffle, and a slight current of air allowed to pass over it, until in about 10 or 15 minutes no sulphurous fumes are given off from the assay. It is then taken out of the muffle, the powder brushed carefully into a cast-iron or bronze mortar, ground finely, and at the same time again mixed with 15 grains of graphite or coal-powder, and placed in the fire-clay cup. A second roasting similar to the first is now accomplished, and when no smell of sulphurous acid can be perceived upon stirring, and the mass has an earthy appearance, which is generally the case in 15 minutes, the assay is taken out and allowed to cool.

When lead or antimony is present, these roastings must be performed with great care, since by raising the heat too high, a partial melting ensues, and the atmospheric oxygen ceases to penetrate the mass.

2nd. *Melting for crude copper.* The assay, after the process of roasting, holds the copper, lead, iron, zinc, tin, &c., in the state of oxides, while the earthy impurities remain to a great extent unchanged. The present melting is accomplished for the purpose of turning as many as possible of the substances that, besides the copper, compose the assay, into the slag, and at the same time to collect the partially purified copper in a button. For this purpose borax and powdered glass are the most active re-agents, forming a readily fusible slag with the earthy impurities and most of the oxides; and, when the proper proportions are present, without acting materially upon the easily reducible copper, which, through the action of the black flux, gives up its oxygen, and by reason of its greater weight falls to the bottom of the vessel, and unites in a single mass.

A crucible having the form shown in fig. 11, is used. To charge it, the roasted assay is carefully removed from the fire-clay dish into a mortar, and mixed with 60 or 70 grains of black flux. This is poured into the crucible, and upon it are thrown, without mixing, 120 to 140 grains of black flux, then 24 to 30 grains of powdered glass, and 15 to 18 grains of borax. This is covered by a layer of common salt (140 to 200 grains), and lastly a piece of charcoal half an inch square is added. For the purpose of forming a more fluid mass, and assisting in the collection of the copper, an addition of 5 to 15 grains of metallic arsenic is made with the glass and borax, when the ore is quite rich, and no lead is present.

The crucible is now covered as shown in fig. 11, and placed in the muffle. A red heat is first given, which towards the end of the operation is raised to white, and in 30 or 40 minutes the smelting may be deemed complete. The crucible is taken from the fire, and, after cooling, is broken with a small hammer, and the copper, mixed with a number of impurities, is found in a well-defined button at the bottom. This button should have no dark crust of sulphides around it, and the slag in which it is inclosed should appear glassy and dark green, without any disposition towards redness.

3rd. *Refining.* This process has for its object the purification of the coarse copper button, of as many as possible of the various substances with which the last process has left it combined. It rests on the property possessed by copper when in a melted condition, and exposed to the action of heated air, of remaining unoxidised as long as iron, lead, arsenic, bismuth, antimony, tin, zinc, nickel, and cobalt, are present. These metals are turned into oxides in such a case, and when borax is at hand, are taken up and carried away as a fusible slag.

The button is wrapped in a piece of paper with an equal weight of borax, and placed with a pair of long tongs upon a cup of fire-clay (generally made by breaking a piece about 2″ long and 1½″ wide out of the side of a crucible, fig. 11), which has already been laid in the muffle, and by surrounding it with glowing coals brought to a high red heat.

The button melts in a few minutes; and by opening the door of the muffle a stream of air is allowed to pass over the fluid. The oxides of the alloying metals form, collect on the surface, and produce a play of colours; and at length the button, having lost much of its impurity, becomes greenish, usually sinks beneath the borax, and, on account of the higher smelting point of copper, becomes solid. The cup is now taken from the muffle, and cooled by dipping it slowly into water. The copper is found in a button among the slag; it should be well formed, bright, and malleable, and when possessed of these qualities may be at once weighed, and the per centage of copper in the ore calculated.

III.—ESTIMATION OF COPPER BEFORE THE BLOW-PIPE.

This method, as I have before remarked, can only be successfully carried out by a skilful hand, and after some experience. But the fact that all the instruments and re-agents necessary for determining the amount of copper in any of its compounds, may be packed in a space not larger than an ordinary dressing-case, and thus carried on long and difficult journeys, is sufficient to commend it to a nation whose members may be found measuring and estimating in all sections of the earth's surface.

In principle it does not widely differ from the common German method of assaying, as just described. The instruments and re-agents necessary to accomplish it have been spoken of in Chapter III., or will be mentioned in the course of the following description. The decimal system of weights and measures has been adopted on account of their peculiar adaptation to the wants of the experimenter in quantitative blow-piping.

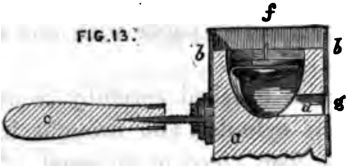
The course of this assay divides naturally into three processes:—

1st. *Roasting.*
2nd. *Melting for crude copper.*
3rd. *Refining.*

1st. *Roasting.* The ore, or product of the furnace, which is to be assayed, is finely powdered in an agate mortar, and, upon a balance which will turn with 0·1 milligramme when loaded with 2 grammes, 1 decigramme is weighed with care, and mixed in a mortar with three times its weight of charcoal powder. The mixture is removed with a camel-hair pencil from the mortar to a clay cup (shown in the drawing), which has been washed internally with a watery solution of the red oxide of iron.

An apparatus is now necessary, having the construction shown in the accompanying drawing, and

FIG. 13.



which is in fact a miniature roasting furnace. *a* is a piece of firm charcoal hollowed at the top, and pierced with the opening *d*; *b b* is a sheet-iron holder, having a hole at *e* corresponding with the opening *d*. It is furnished with the handle *c*, which may be made, by screwing, to press against and hold the charcoal, *a*, in its place. *e* is a roasting-cup of clay, 20 mm. in diameter, and 7 mm. deep, which rests within, and is held by a platinum ring that is fastened to the side of the holder by means of the hooked ear *f*.

The mixture being placed, as described, in the cup *e*, the blow-pipe flame is directed through the opening *d*, at first gently, subsequently with more force till the cup is raised to a red heat. When any doubt remains that the sulphur is not entirely driven from the assay, more coal powder is added, and the heat continued. At the end of ten minutes the roasting is generally complete, and the next operation may be proceeded with.

2nd. *Reduction of the Metallic Oxides, or melting for crude copper.* The roasted powder is removed from the clay cup to an agate mortar and mixed with 100 to 150 milligrammes of dry soda; about 50 milligrammes of boracic acid, and 30 to 50 milligrammes of pure lead. When the ore itself holds much lead the last addition may be omitted. A strip of filter-paper, which has been dipped in a solution of soda and dried, is wrapped upon a piece of wood 7 millimetres in diameter, and a hollow cylinder of paper with one closed end is thus formed.

The mixture is brushed carefully from the mortar, enclosed in this cylinder, and brought into an appropriate hole in a firm piece of charcoal. The smelting is commenced by directing a *reducing* flame (see Chap. III.) upon the assay, and continuing it till the mass becomes fluid and all the copper has collected in a button at the bottom. This operation requires from 3 to 5 minutes, and after it is concluded the button of *coarse copper,* whose principal impurity is lead, is broken from the slag by hammering it between paper.

3rd. *Refining.* The coarse copper button is not refined before the blow-pipe with borax, as is the case in the German assay. In place of this flux boracic acid is used; this substance has the property of causing the lead to be readily oxidised and turned into slag. A hole is made in the end of a piece of charcoal, and a quantity of boracic acid equal in weight to the metallic button is melted in it to a pearl. The button is then laid in the melted acid, and first treated with a reducing and afterwards with an oxidising flame; the process is continued till the lead has absorbed oxygen and been taken into combination with the borax, and the grain of copper remaining assumes a greenish colour.

The grain is now taken with a pair of forceps from the soft slag, and its purity proven by its malleability beneath a hammer.

If the slag by its redness shows that some copper has been taken up, it is only necessary to direct a reducing flame upon it for some time, until the copper collects in a grain, from which the lead is driven by treating it with an oxidising flame. The grain of copper thus obtained is placed with the larger one, and both are weighed; the expression of this weight in milligrammes gives the per centage of copper in the substance assayed.

The refining operation requires about 10 minutes, and the entire process of determining the per centage of copper in an ore by means of the blow-pipe, may be finished in from three-quarters of an hour to an hour.

IV.—THE ESTIMATION OF COPPER BY THE HUMID ASSAY.

The complicity and partly the cost and inaccuracy of the foregoing methods of estimating copper make it sometimes expedient to adopt the humid assay, for which various processes are in use. The most trustworthy of these are the following.

1st. *The Swedish method.* This is especially adapted for compounds containing little or no arsenic, antimony, bismuth, or tin; but even where these metals exist in the ore, results are generally obtained which equal in accuracy those by the methods described in the sections I., II., and III. of this Chapter.

From 50 to 60 grains of the sample are weighed and roasted in one of the fire-clay dishes, fig. 12, in the manner detailed in the description of the German method of assaying. When there is no doubt that the ore is composed entirely of the oxides and carbonates, this roasting may be dispensed with. The powder is now placed in a porcelain cup, and just covered with concentrated hydrochloric acid. After this has been well stirred and evaporated nearly to dryness, strong sulphuric acid is added to the amount of about 20 drops, or till the odour of hydrochloric acid is no longer perceived. The assay is again heated till the vapours of sulphuric acid begin to develop, when the dish is partly filled with water and kept warm for some time, in order that all the sulphate of copper that has been formed may be brought into solution. All the copper having been taken up, the solution is filtered in order to separate it from the earthy impurities that have collected at the bottom of the vessel, and the filter is washed with warm water until the fluid passing through is no longer acid.

A piece of pure zinc is then brought into the bluish solution, and by its electro-positive action the copper is thrown down in the form of a powder, while at the same time an equivalent quantity of zinc is dissolved and the bluish colour disappears. When all the copper has been precipitated, no red tinge will be given to a plate of iron when dipped into the solution. By this simple test the time for removing the zinc may be determined, and the remaining particles of that metal are picked out with a pair of forceps, and washed carefully of all the copper that may have adhered to them. The copper powder is now washed repeatedly with distilled water, until all the soluble salts have been removed, and then dried at a temperature of 212° and weighed. If no oxidation has taken place, the weight thus obtained may at once be used for estimating the per centage of copper in the ore; but, as has been previously remarked, this metal in the state of fine division is readily attacked by the air, and hence it is better to change the powder at once into the oxide, by heating it for a few minutes in an open dish, and subsequently weighing the compound. The amount of pure copper is then obtained by the following proportion:

100 : 79·8 : : weight of oxide : weight of the copper in the assay.

Then, the weight of ore originally taken : weight of copper in the assay : : 100 : the per centage of copper in the ore.

2nd. *Pelouze's method of determining copper.* This method rests upon the fact, that from a solution of copper to which an excess of ammonia has been added, and thus the characteristic blue colour produced, the copper may be entirely precipitated by the addition of a solution of the sulphide of sodium, and as the last trace of copper falls, the blue colour disappears. It is evident, since the amount of copper precipitated must always be proportional to the amount of sulphide of sodium added, that, if we know the quantity of copper which each grain of the test-solution will throw down, and at the same time the *number of grains* we have added of the solution, the quantity of copper in the second or ammoniacal solution may be calculated by a simple multiplication.

To determine the *number of grains* added, it is only necessary to pour the fluid from an accurately graduated glass tube, each degree of which corresponds to a certain number of grains, and notice the position of the surface before and after the addition.

To determine the quantity of copper which each grain of the test-solution will throw down, a weighed portion, say one grain, of perfectly pure copper is dissolved in nitric acid, and ammonia added till a clear blue colour appears; the test-solution is then poured in drop by drop from a graduated tube, till the blue colour disappears, and the amount necessary to precipitate a grain of copper may be at once accurately read.

This amount being carefully noted, the experimenter is prepared to proceed with his assays. From 10 to 15 grains of the ore or other compound are weighed and dissolved in nitric acid or *aqua regia* (consisting of two parts of hydrochloric acid and one part of nitric acid); the solution is made clear blue by the addition of an excess of ammonia and heated to about 160°.

The standard solution of sulphide is then slowly added from a graduated tube, and from time to time the solution of copper stirred, and furnished with ammonia. At length the blue colour disappears, the number of grains used of the standard solution are read by observing the number of degrees through which the solution in the graduated tube has sunk, and by the following proportions the quantity of copper present is calculated:—

The quantity of test-solution necessary to throw down one grain of copper : the quantity of test-solution used : : 1 : the number of grains of copper present.

Then: the number of grains of ore or compound originally dissolved : the number of grains of copper present : : 100 : the per centage of copper in the ore or compound.

Numerous determinations may be made with the same standard solution; and since but one weighing is required for each assay, and the remaining manipulations are quickly performed, this method may be advantageously used where a great number of estimations are to be made at the same time. Its accuracy is affected by the presence of cobalt, nickel, mercury, and silver, though the latter metal may be made harmless by the addition of a few drops of hydrochloric acid.

Methods similar in character to that of Pelouze have been proposed by Mohr and others, but none is at the same time more simple and more satisfactory in its results.

An ingenious plan has been used in Central Germany and also in Swansea for the determination of copper where the amount present does not exceed one per cent. of the substance to be examined, it rests upon the *depth* of the shade of blue in the ammoniacal solution above mentioned, which is compared with the shades of a series of similar solutions, each containing a known proportion of copper. To the one-thirtieth of one per cent. reliable estimations can be made by ths means.

CHAPTER VII.

ON THE NATURE AND PREPARATION OF FUELS: WOOD, CHARCOAL, MINERAL COAL, COKE.

THE question of fuel with the metallurgist is one of primary importance. By far the majority of processes which he is obliged to carry out depend directly on the application of heat; and upon the abundance and cost, as well as upon the nature of the materials that generate this heat, will depend largely the profit of his operations and the excellence of his productions. The position of the supply of fuel has as much to do with fixing the location of the smelting works as the position of the metallic district, and indeed much more when the mineral reduced is rich in copper.

The copper blocks of Lake Superior are carried hundreds of miles to be smelted in the neighbourhood of the coal basins of Ohio and Pennsylvania; while Swansea, situated in the immediate vicinity of abundance of coal, collects ores from every quarter of the globe. The wisdom evinced by the long established custom of sending Cornish ores to Wales to be reduced is clear, when we learn that, according to the old manner of smelting, it required 20 tons of coal to produce one ton of copper when the ore held 8 per cent. of metal; hence, instead of taking 20 tons of fuel to

Cornwall, 12½ tons of ore were sent to Wales. Poor ores of copper on the contrary will not pay for wide transportation: thus the smelter of the Ural gathers charcoal for his furnaces from long distances; and the copper schists of Mansfeld in Prussia, are reduced near the mines, partly with coke brought from England. The quantity and price of fuel further, to some extent, decide the nature of the process adopted; thus, where coal is very abundant, the wasteful but convenient reverberatory furnace is employed, as in Wales and in some parts of the United States. Where a less generous supply is found, the cupola furnace is often used; and where still less can be obtained, the "wet way" is sometimes considered the most profitable, as at Rio Tinto in southern Spain.

By *fuels* the metallurgist understands those combustible substances that can be used in his processes for the production of heat. By far the most important are *wood, charcoal, mineral coal* and *coke,* to which, though holding a subordinate position, may be added *brown coal* and *turf,* and the products of charring the same. The two first in the list are natural products, and are made up essentially of carbon, oxygen and hydrogen, the second two are formed by art from the first, and are composed almost entirely of carbon, but in all more or less of other substances is invariably present, some of which remain after the combustion of the fuel, as the *ash.*

The process of burning consists essentially in the combining of the carbon and the hydrogen of the fuel with the oxygen of the fuel itself, and that of the atmosphere; the compounds produced when the process is *perfect, are principally carbonic* acid and water. It has been shown that the quantity of oxygen absorbed from the atmosphere by the combustion of a fuel, which may be readily determined by what is known as Berthier's process, may be taken as a measure of its heating power. The following table, the result of the discovery of this law and process, is given by Scheerer, to show the relative amounts of heat produced by the complete burning of equal volumes of certain well known combustibles, pure carbon (diamond) being assumed as 100, the other numbers express percentages.

Pure carbon	100·00
Good mineral coal	33·00
Olive oil	30·20
Alcohol	19·80
Dry wood	5·26
Charcoal	4·94
Wood, with 20 per cent. moisture	4·94
Hydrogen	0·0077

When a fuel is brought in connection with the atmosphere to a glowing temperature, it burns either *with flame*—as is the case with wood, most kinds of mineral coal and compounds holding much hydrogen—or *without flame,* as is generally the case with coke, charcoal and some varieties of mineral coal that are poor in hydrogen. The presence or absence of the qualities producing flame, has much weight in the choice of fuels for particular chemical operations, and influences essentially the form and dimensions of the furnaces in which such operations are carried out.

THE COMPOSITION AND PREPARATION OF WOOD.

Although it has been proved by repeated experiments *that the composition* of wood is almost the same in all species of plants, yet a great variety is found to exist in respect to the hardness, weight, ease of kindling, and power of heating, which originates in the difference of structure displayed by dissimilar species. In general, green wood contains from 37 to 48 per cent. of watery fluid or sap, which in the atmosphere does not entirely dry out, since the best air dried wood continues to hold from 16 to 25 per cent. of moisture, known as *hygroscopic water*. The ash of wood consists of potash, soda, lime, magnesia, sesquioxide of iron, oxide of manganese, carbonic, phosphoric, silicic, and sulphuric acids, and chlorine; its amount varies with the species of wood, and with the nature of the soil in which the plant grew, but it is seldom under 0·5 or over 5·0 per cent. By the drying process the effective power of wood is largely increased, since thus the water is carried away that must otherwise be evaporated in the process of combustion. Hence the most proper time for cutting this kind of fuel is in early spring, that it may be piled to dry during the summer. Wood may be preserved for a great length of time either in dry air or under water, but when subjected alternately to the action of these elements it gradually absorbs oxygen, forms carbonic acid gas, loses its firmness and rots, becoming worthless as a fuel.

For some metallurgic purposes wood must be dried at a high temperature in kilns, that the hygroscopic moisture may be driven off as completely as possible. With such kiln-dried fuel when split into thin sticks, and placed on the grate in small quantities and frequently, the greatest amount and highest degree of heat that can be obtained from wood, is secured. But at the same time just enough air must be admitted, since too much will cool down the furnace, and too little will allow the gases formed to pass off unburned. Hard woods have all their volatile combustible constituents driven out soon after kindling, and a thick coal remains which gradually consumes without flame. Soft woods on the contrary usually give flame during the whole course of their burning, hence where operations are to be accomplished requiring this peculiarity, the soft wood should be preferred, and among these the pines furnish a wood rich in resins and producing the longest flame. The copper smelter uses wood to kindle more solid fuel in various processes, for roasting his ores in furnaces where an extensive flame is necessary, and when working in the wet way to evaporate solutions in peculiar long reverberatory furnaces. The operation of *poling*, the last stage in the process of refining by the Welsh method, is performed by stirring the melted metal with long poles of green ash or oak.

ON THE NATURE OF CHARCOAL.

When wood is exposed to a high temperature and at the same time protected from the action of the air, it gives off various fixed gases, much water, several acids, and some tar. When this operation, which is called *dry distillation*, is carried on with rapidity, about 14 per cent. of the weight of the wood remains as charcoal, after all the volatile compounds have escaped. When however the process is accomplished slowly, as much as 24 to 28 per cent. of charcoal is obtained from the same wood. This remarkable difference originates in the peculiar decomposition that takes place when steam is *brought in contact* with *highly heated* coal, a large portion of the solid carbon passing off in the form of carbonic oxide and carbonic acid gas. This is a fact of the utmost importance to the charcoal burner, who has discovered without being able to explain the reason, that in order to obtain the largest quantity of coal, he must perform his charring by allowing the heat to act gradually, and never rise higher than can be avoided.

Good charcoal retains the form and structure of the wood from which it is made. It may be distinguished by its clear fracture, glancing bluish black surface and the property of giving a ringing tone when struck. Charcoal incompletely burned may be known by its reddish appearance on the longitudinal fracture, and by the dulness of the sound produced when it is struck. Charcoal possesses in a fresh condition the power of absorbing to the amount of 10 to 12 per cent. the gases to which it may be exposed, and upon this fact rests the phenomenon it occasionally exhibits of spontaneous combustion; the air being absorbed by the fine coal, and condensed in its pores, sets free enough latent heat to bring the mass to a glowing temperature. Although the weight of charcoal obtained by the usual methods of charring is generally not over 25 per cent. of the wood used, yet in regard to volume it suffers a much smaller loss, so that by properly conducted processes it should afford 60 to 70 per cent. of the original mass of wood. The object of charring wood is to obtain a larger amount of non-flaming combustible matter within a given weight and bulk of fuel, thus facilitating transportation, and supplying the concentrated heat required for many metallurgic operations.

ON THE MANUFACTURE OF CHARCOAL.

Charcoal is produced on an extensive scale by two methods.

1. By arranging the wood in large piles, and covering it with a layer of loam or earth, and thus by allowing, after kindling, but a limited supply of air, securing a slow combustion of a portion of the wood, which furnishes heat for the dry distillation of the remainder. This method includes the preparation of charcoal in *mounds* and piles.

The best time of year for this work is in summer or autumn, since then the weather is most regular, the days are longest, and the materials necessary for performing it are easiest obtained. The *mounds* are formed by piling in a circular form, on a surface which has been proven to be sufficiently dry and firm, from 15 to 25 cords of wood, covering it first with the charcoal dust or *breeze* obtained from a preceding operation, then with moss, leaves and similar materials, and packing upon this an outer and more solid covering of earth. The wood is then kindled through an aperture that has been left for the purpose, and which is then tightly closed. The workman now carefully regulates the rapidity of the combustion by opening or closing holes admitting air to the burning mass. At the end of eight days for small mounds, and twelve to sixteen days for large, the charring is generally complete. The fire is then smothered by piling sand and clay tightly over it so that no air can gain admission. When 25 or 30 hours have elapsed the charcoal may be removed and is now ready for the smelter's use.

2. In regions rich in wood, such as occur in Sweden and Russia, a system of charring in *piles* is usual. Logs 6 to 12 feet in length, and sometimes 12 inches in diameter, are laid one over the other until a pile 20 to 60 feet long is formed; this is covered with layers of sod and earth, as above described, and by a course not differing much from that pursued in charring in mounds, a coal is obtained which is said to be of superior quality.

The gaseous and fluid constituents, of which wood has a valuable store, are lost by the usual plan of charring in mounds and piles. A third system is sometimes adopted, where the valuable fluid and soluble elements are collected. For this purpose the process is conducted in permanent furnaces provided with the proper apparatus to lead away and condense the gases produced. The heat necessary to char the wood is either developed by the combustion of a portion of the material in the furnace, or by a separate fire upon the exterior. The quantity of charcoal obtained from ordinary wood by this process is occasionally 27 per cent. of the original weight, but at the same time 5 per cent. of the same amount is required to supply the requisite heat.

The copper smelters in some parts of the world are almost entirely dependent upon charcoal for their means of obtaining heat. In Wales its use is very limited, but in continental processes, it is employed continually in the cupola furnaces, occasionally in the reverberatory furnaces, and as a fuel and re-agent in the process of refining it acts an important part.

ON THE NATURE OF MINERAL COALS.

The fossil fuel dug from formations lower in the geological series than the Tertiary, has received the general name of Mineral coal. It is found chiefly in layers or seams in what is known as the coal formation, but sometimes, and in limited quantities, in the strata above and below that remarkable deposit. There are various sorts of mineral coal differing in their appearance and composition. It is sufficient for the metallurgist to distinguish four classes that are founded on the behaviour of the mineral when exposed to fire, and therefore closely depend on its chemical composition.

Caking Coal, upon being subjected to the action of heat softens, undergoes a sort of fusion, the various pieces adhere together and the original structure of the coal is lost.

Sinter Coal, has in a less degree the property of caking in the fire, and by coking the original structure of the mass is not entirely destroyed.

Sand Coal, does not cake on the fire, and when coked does not agglomerate, as in the case of the two preceding divisions.

Anthracite, on account of the absence of volatile ingredients in its composition does not fuse when heated, and in many of its properties it approaches the coke made from other sorts of coal.

The following analysis made by various chemists will exhibit accurately the chemical differences that exist among the several classes :—

			Carbon.	Hydrogen.	Oxygen.
Sand coal,	from	St. Girone	76·05	5·69	18·26
,,	,,	Bloncy	78·26	5·35	16·39
Sinter coal	,,	Commentry	82·92	5·30	11·78
,,	,,	Céral	84·56	5·32	10·12
Caking coal	,,	Lancashire	85·81	5·85	8·34
,,	,,	Mons	87·09	5·63	7·30
,,	,,	Newcastle	89·19	5·31	5·56
Anthracite	,,	Lanquicke, Glamorgansh.	91·44	3·84	3·59
,,	,,	Swansea	92·16	3·66	3·88
,,	,,	Pennsylvania	94·89	2·55	2·56
,,	,,	Macot	97·23	1·25	1·52

Numerous experiments by Regnault show that each of the four classes may be considered to have the following average composition and specific gravity :

	Carbon.	Hydrogen.	Oxygen.	Spec. Gravity.
Sand coal	77	5	18	1·34
Sinter coal	83	5	12	1·30
Caking coal	87	5	8	1·36
Anthracite	95	3	2	1·50

The amount of ash left by mineral coal after complete combustion varies from 1 to 20 per cent.; the average may be taken at 5 per cent., except anthracite which contains, as a rule, still less. When compared with equal volumes of wood the heating power of mineral coal may be generally reckoned as 5 to 1, and when compared with the same weight of wood as 15 to 8. In order to obtain the greatest effect from coal it must be divided into pieces of proper size, burned on a grate of an extent proportionate to the amount of ash produced, in a layer not too thick to prevent complete combustion, and at the same time must be supplied with sufficient air by means of a chimney or blower. Mineral coal is used by the metallurgist for roasting the ore in heaps or furnaces, for smelting in reverberatory furnaces and for boiling solutions. The softer varieties are not generally employed in cupola furnaces on account of their baking together and forming a mass that is difficult for the air to penetrate. Anthracite, however, on account of its not possessing this property may often be used with good effect. The mineral coal of Wales is for the copper smelter of prime importance, since it forms in the large establishments at Swansea the chief material for producing heat. Two varieties are there distinguished, a *strong burning* coal, and a *weak burning* coal, which act very differently in the furnace. The *strong* coals have generally a large amount of volatile matter and give a long hot flame; the coke formed during its combustion is light and spongy, and allows the air to pass free through it. The *weak* coals may resemble anthracite in containing little volatile matter and hence giving an extremely short flame that scarcely reaches the contents of the hearth, or they may have a very large and diffuse flame that gives but little heat. The strong coals are often used alone, but the weak must be mixed with the strong to secure a good result in the furnace. The composition of the ash of their coal is considered a subject of much importance by the furnace men, on account of its influence on a peculiar and very economical plan which they have devised for securing complete and effective combustion of all sizes of coal without the usual destruction of the iron grate bars upon which the fuel generally rests. This plan consists in allowing the ash to cake or clot together into cellular fragments called *clinker*, which collects in the bottom of the fireplace, and while pervious to the draught which it heats during its passage, forms a support for the fire, and prevents much of the small coal from being lost by falling into the ash-pit.

ON THE NATURE OF COKE.

For many purposes the metallurgist requires a fuel that is devoid of those constituents which melt and volatilise at a low temperature, thus diffusing the heat and producing a clotting which prevents the air necessary for combustion from properly penetrating the burning mass. Such constituents which are more or less abundant in mineral coal, are separated by a process known as *coking,* in the course of which the sulphur that also exists in most coals and for many metallurgic uses is very disadvantageous, is partly driven off. Anthracite which is itself a sort of natural coke, is not adapted for this process, but the other three varieties of mineral coal with the properties of which the student is already acquainted, may be submitted to it with more or less profit, and the coke produced though differing according to the nature of the coal in physical qualities, is when considered chemically, very similar.

Good coke consists of	85 to 92	per cent.	of carbon
	3 to 5	,,	ash
	5 to 10	,,	hygroscopic water.

The ash is not essentially different in composition from that in the coal from which it is made, but it is always found in a larger proportion; thus coke having 10 to 12 per cent. ash is made from a coal with but 5 or 6 per cent. The water which it attracts, like charcoal, from the air, may amount occasionally to 20 per cent. Compared with an equal weight of pure carbon, coke gives ·85 to ·95 as much heat. Caking coal produces a porous, iron grey coke with a silky, and sometimes almost metallic glance, and in the process of coking it melts, forms a doughy mass, and, on account of the numerous bubbles that are formed within it, increases considerably in volume. Sinter and sand coal, not melting together, remain nearly unchanged, in form and volume, when subjected to the same influences. The specific gravity of the three sorts of coke, and their heating power, when compared with equal volumes of pure carbon, are, according to Scheerer, as follows:—

	Spe. Grav.	Specific Heat.
Coke from sand coal......	0·48	0·46
,, sinter coal ...	0·43	0·41
,, caking coal ...	0·35	0·33

ON THE MANUFACTURE OF COKE.

As is the case with wood, so with mineral coal,—a rapid driving off of the volatile ingredients produces a loss which may be prevented by gradual heating; in fact the process of coking is, in most respects, similar to that of charring, and the general principles of one apply to the other.

Like charcoal, coke is made by three methods: in *mounds*, in *piles*, or in *furnaces*. By the first two methods coal is generally used which has not been reduced to very small fragments, by the last, powdered coal is also brought to the condition of coke.

Coking in mounds and piles. This is done, when the coal is in sufficiently large pieces, by building, in the centre of a dry sandy spot, a simple brick chimney, 3 or 4 feet high, furnished with numerous apertures at its lower end, and with an iron plate capable of closing the upper opening. Radiating from the chimney as a centre, six or eight small canals are built of large pieces of coal or of bricks laid closely together to furnish passage for the air. Upon and around these canals the coal is heaped in a circle, 18 to 20 feet in diameter, and curving gradually to the chimney, where it is 3 to 3½ feet high. A coating of damp, powdered coal, or *breeze,* about 3 inches thick is laid evenly on the surface, and fire is started in the central part, and allowed to extend itself gradually toward the periphery. At the end of 48 or 50 hours, vapours and smoke cease to issue from the chimney, the coking is considered complete, and further combustion is prevented by closing all apertures that can admit air to the interior of the heap. The fire is thus smothered, and as soon as the coke has cooled it may be drawn and is ready for use. In coking in *piles* the process is essentially the same as that described; the most important difference being in the amount that is thus manufactured together. The form of the piles is generally rectangular, 10 to 12 feet wide, and 100 to 150 feet long. When it is necessary to coke powdered coal by this means it is moistened so as to adhere slightly together, and built in narrow heaps around smooth logs of light wood; after the piles have been fully formed and pressed down, the logs are carefully drawn out, leaving numerous holes for the passage of air. It is then covered with a layer of *breeze,* set on fire, and allowed to burn until fully coked, when it is quenched by drenching it with water.

Coking in furnaces. Coal "small" is more conveniently coked in furnaces than in heaps, and in some localities coal is powdered by machinery before subjecting it to the fire, that a more homogeneous coke may be produced. The furnaces may either be open or closed. The *open*, or *"field" furnaces* consist of four simple walls, about 4 feet high, enclosing a rectangular space about 8 feet broad and 100 or 200 feet long. The side walls are furnished with apertures through which smooth logs are thrust. The coal is packed into the space between the walls, furnished with a cover of *breeze* or loam, and after the logs have been drawn out, thus leaving the mass penetrated with air-canals, kindled and allowed to burn for 8 or 9 days, when the process is generally completed.

The number of *closed furnaces* that have been proposed and tried for making coke is very large, and where the demand for this species of fuel is extensive, one or another of these contrivances generally takes the place of the *heap*, or *open furnace* plan. According to the older systems these furnaces are constructed in the form of an oval or circular vault, with an opening at the top, through which the coal is thrown, that can also answer the purpose of a chimney, and a door at one side from which the coke is drawn by hand. This plan has, in many places, been superseded by furnaces constructed like long vaults about 3 feet broad, 4½ feet high, and 25 feet long, which are built side by side, forming a long row. Two holes in the crown of the arch of each furnace serve to charge this furnace with coal which, after being spread evenly along the vault, kindles by the heat of the glowing mass in the neighbouring furnace. Through small holes in the wall the workmen observe the progress of combustion within; when, at length, a red glow takes the place of light-coloured or bluish flames, the process is considered concluded; the large doors at each end of the vault are opened, and, by means of a huge pusher, worked by hand or steam-power, the entire mass is slowly shoved out into the cooling yard, where it is quenched and, at the same time, dispossessed of the greater part of its sulphur, by throwing water upon it. The amount, by weight, obtained from the different varieties of coal averages, according to Scheerer, for

Sand coal......	from	55	to	65	per cent.
Sinter coal ...	,,	60	,,	70	,,
Coking coal...	,,	60	,,	80	,,

The coke produced in furnaces is solider than that made in mounds or piles, and weighs about 3 pounds more per cubic foot.

Good coke may be known by its homogeneousness, and the presence of no fragments of slate; by solidity or the property of withstanding pressure, a clear bright colour, and a small per-centage of ash and sulphur. For the copper smelter, coke is capable of taking the place of charcoal in most cases; he uses it when a flameless, unmeltable, and highly concentrated fuel is required, as in the cupola furnace. Much more rarely it is employed for roasting in heaps, but, on account of its producing little or no flame, it is not adapted for exclusive use in the reverberatory furnaces.

CHAPTER VIII.

On Furnace Materials; the Apparatus in which the Reduction of Copper is performed. The General Principles of the Processes employed in the Metallurgy of Copper.

ON THE MATERIALS USED IN THE CONSTRUCTION OF FURNACES.

The durability of a furnace depends essentially upon the nature of the materials from which it is constructed. No substance with which we are acquainted is capable of completely withstanding the action which must go forward in the interior of a smelting furnace, the frequent changes of temperature, the intense heat necessary to melt refractory ores, and the dissolving power of the gases and fluids that are there produced. The compound of silica and alumina known as fire-clay possesses in a higher degree than any other common substance the properties necessary to enable it to resist the effects of these destructive agencies, and it is generally employed for forming the lining of furnaces, and the construction of such parts of metallurgic apparatus as are directly exposed to the action of intense fire. This material is usually moulded into bricks of the common shape, or into blocks adapted to particular parts of the furnace to be constructed, and baked firmly, before coming into the hands of the metallurgist; and since all clays on account of a loss of combined water, or a partial fusing together, decrease in volume or crack when exposed in their natural state to a high heat; all good fire-bricks are made partly from clay, that previous to its being moulded is strongly calcined and reduced to a powder.

The English clay has long held a high place in the opinion of European smelters; on the continent Belgium furnishes that most generally prized. The best fire-bricks come to Wales from the neighbourhood of the town of Stourbridge in South Staffordshire; they are 9 inches long, 4½ inches broad, and of such thickness that two of them extend 6 inches when placed together with a thin stratum of mortar between them. Less valuable bricks are made in Wales from clay found in beds in the coal formation; and Flintshire furnishes a third sort to the Swansea market.

A clay from near Stourbridge, analysed by Berthier, afforded him

Combined water	10·3
Silica	63·7
Alumina	20·7
Oxide of Iron	4·4
	99·1

A very refractory fire-stone has been formed by working together one part of clay with two or three parts of quartz sand and moulding the mixture. Such stones do not shrink perceptibly after having been baked, and they have the advantage of being easily fashioned into any desirable form with the saw and chisel. A mixture of 1 part of unburned clay, 1½ to 2 parts of burned clay, and 1 to 1½ parts of graphite, or black lead, forms a mass that when once coated with a thin glass that excludes the air from its surface, is almost indestructible.

Nature furnishes a number of rocks which being composed chiefly of the same elements as the fire-clay possess in various degrees its refractory qualities. These are known as *fire-stones*, and among them may be reckoned sandstone, clay-slate, talcose slate, mica slate, and gneiss. The first mentioned is as a rule the best, especially when composed of quartz sand bound together with a silicious cement. No general rule can be given for recognising a good fire-stone; the best plan is to expose a fragment of the mass in question to the action of a furnace and observe the effect produced. Mortar for building the interior of furnaces should be made of the same materials used to form the fire-brick, by bringing it with water to the condition of a thin paste. The common lime mortar should by no means be employed where the work is to be exposed to a high heat, because under such circumstances it unites with the silica, producing a somewhat fusible compound. The hearths of reverberatory furnaces, and other parts of the smelting apparatus are frequently constructed of a refractory mass which without being previously moulded, is worked on the spot and in the furnace itself, to the required form. In Swansea a quartz sand used in its natural state, not only makes up an essential portion of some of the furnaces, but by gradually uniting with the mass melted upon it, plays an important part as a flux. A mixture called *brasque*, used for forming temporary basins and hearths, into and over which fluid metal and slag are drawn, consists of clay and powdered charcoal or coke, in nearly equal proportions.

GENERAL DESCRIPTION OF THE APPARATUS IN WHICH THE METALLURGIC PROCESSES OF COPPER SMELTING ARE PERFORMED.

Almost every copper-reducing region has furnaces and other apparatus more or less peculiar to itself. These varieties arise from the system of reducing the metal which may be customary, the nature of the ores or fuel, or the judgment of the smelter. But all the forms may readily be referred back to four types, which are distinctly different in the arrangement of their various parts, and are also distinguished from each other by the nature of the processes for which each is particularly adapted.

In the description of special processes which will be found in another part of this treatise, the apparatus required for each will be given in greater detail of material and measurement; here will be found a recital of the general characteristics of the four classes to which they all may be referred.

I.—*Apparatus for roasting where the fuel is mixed with the ore.* II.—*Reverberatory furnaces.* III.—*Cupola furnaces.* IV.—*Refining hearths.*

I. APPARATUS FOR ROASTING WHERE THE FUEL IS MIXED WITH THE ORE.

These are exceedingly simple, sometimes consisting of a smooth pavement, or dry floor of clay, upon which the ore is piled in pyramidal heaps, the larger pieces being placed under, the smaller above, the whole penetrated by temporary canals or chimneys, to permit a better circulation of air, and sometimes covered by a coating of powdered ore. The fuel forms the foundation and serves to commence the combustion of the sulphurous constituents which are often sufficiently abundant to prolong chemical action and keep the mass glowing for several weeks.

Another common form consists of a rectangular space surrounded on three sides by walls, and capable of holding a pile of 5 or more tons of ore. The fourth side is left open to allow easier charging and discharging. Small chimneys penetrating the mass, and the foundation of fuel, answer the same purposes as they do in the first-mentioned plan. An addition of a separate fire-place is sometimes made to these open roasting floors, by supplying which with fuel the process of roasting is completed. A third arrangement is occasionally employed for roasting furnace products. It consists of a vault about 9 feet long, 6 high, and 4 broad, one end of which is left open for the introduction of the charge of ore and fuel, but is subsequently closed with a dry brick wall. A permanent chimney carries off the gases and supplies a certain amount of draught to increase the rapidity of the roasting.

II. REVERBERATORY FURNACES.

This is the most important form of furnace used by the copper smelter. Its plan of construction is various, and depends on the nature of the ore to be treated, the fuel employed, and the process to be performed; but the name includes all furnaces with a separate fire-place, a hearth for containing the substance to be treated, situated below a low vault, and in most cases, with a chimney. Fig. 14, page 127, represents one of the English reverberatory furnaces used in Swansea; G represents the grate of iron bars upon which the fuel is consumed; B, the *fire-bridge*, which separates the *fire-place* from the *hearth* or *sole*, S. The gases pass off through the *flue*, F, into the chimney. The flames originating in the combustion of the fuel at G, follow the leading of the arch A, cross the fire-bridge B, and carried forward by the draught generated in the chimney, sweep over the hearth, S, heating and bringing forward chemical changes in the substance which is placed upon it. The flame, whose natural tendency is upward, rebounds or is *reverberated* from the surface of the arch upon the metalliferous mass below, and hence the name of this class of furnaces. The charge is generally brought upon the hearth by allowing it to fall through a hole C, in the vault; and for the sake of greater convenience, these holes have frequently hoppers above them, which being filled, can be emptied at once into the furnace. The furnace has two or more apertures at the side or end, which allow the attendant to stir or otherwise treat the charge while being subjected to the action of the fire, and which also may be employed to draw off the substance after the process is completed. The hearth is occasionally cleared by scraping the charge through a hole, H, shown in the figure, leading into a chamber below, which remains closed while the furnace is in action.

The fire-bars are of iron and are often moveable, so that the workman may stir the fire more readily from below. The vault, the fire-bridge, the interior of the chimney, and all parts intended to be exposed to severe heat, are constructed of fire-brick, while the exterior walls are usually built of the cheaper common clay bricks; all is firmly bound together with iron ties fastened with clamps and wedges. The sole or hearth, S, when the furnace is to be used for smelting, is formed of a mixture of sand and silicious slag; when for an evaporating furnace, a shallow water-tight pan occupies the same place. The metallurgic processes that may be performed in reverberatory furnaces embrace nearly all that are necessary for the reduction of copper from its ores. They may be employed for roasting and for oxidising, reducing and dissolving fusion. They are however expensive to build, and require proportionally a very large amount of fuel, since the flame playing rapidly over the surface of the metal, at S, rushes up the chimney while yet but a small per-centage of its heat has been given off.

III. CUPOLA FURNACES.

A cupola furnace consists of a shaft-like space, having a height greater than its breadth, enclosed in mason-work, and in which the substance to be metallurgically treated is melted, generally mixed, and in intimate connection with the fuel. The height of the furnaces of this class used in copper smelting varies from 6 to 18, and sometimes reaches 25 feet; the air requisite to carry on the process is forced in at the lower part of the shaft by a blowing apparatus usually driven by water or steam. Fig. 16, page 154, may be taken as an example of a cupola furnace; the space, A, represents the *shaft*, *cone* or *body* of the furnace; B, is the opening known as the *tunnel-head* or *throat*, *through which* ore, fuel, and flux are introduced into the shaft and allowed thence to sink towards the *sole*, s. At c, are openings called *tuyères*, through which the air is forced, to supply the combustion which chiefly takes place in the prismatic space, G, which is known as the *hearth*; *e*, is the *eye* of the furnace, through which the melted metal and slag formed in the hearth flow by a narrow channel into the basins, *f f*. The interior wall or *shirt*, *h*, of the furnace is constructed of fire-brick or refractory fire-stone; the outer wall may be of common masonry. The front hearth, *g*, over which the metal flows, is usually formed of coal or coke and clay, in the condition of fine powder. The tuyères, c, are generally made of cast iron; but sometimes, as in parts of Sweden, they are formed of clay. In practice, a tube of slag formed by the cold air rushing in at the tuyères, and impinging against the melted mass, extends from the *nozzel* of the blowing pipe into the hearth, regulating the place where the air enters. This *nose* is of much use to carry the air into the central parts of the furnace, and to protect the tuyères from the destructive action of the hot gases; and its direction, length, and temperature are watched with attention by the careful smelter who regulates by its appearance the proportion of fuel used; hence arises the German metallurgists' adage, "You should seek a good furnace-man behind his furnace."

The cupola furnace is the most economical of all apparatuses used for smelting. The fuel being consumed directly in contact with the ore, subjects it to the most intense action, and the heated gases or flames passing on their way upward through the various layers of mineral, the latter absorbs a greater part of the heat, so that they pass off at the tunnel-head at a low temperature when compared with those that stream up the flue of a reverberatory furnace.

IV. REFINING HEARTHS.

The refining hearth (fig. 19, page 170) is used on the continent for performing some of the last processes in the purification of copper. It consists of a clay mass, *b*, having its upper part properly hollowed into a basin, A. The tuyère, *c*, is furnished with a moveable nozzel, *d*, through which a strong blast of air can be driven at any desirable angle into the basin, A, where the substance to be acted upon is melted. The fuel employed is usually charcoal; the object of the apparatus is generally to carry out a strongly oxidising fusion, and its size may vary so that from 100 to 700 pounds of copper may be treated at once.

ON THE GENERAL PRINCIPLES OF METALLURGIC PROCESSES.

The ore passing in the course of its concentration from the hand of the miner into that of the smelter has arrived at a condition of richness which will warrant a change from its hitherto almost exclusively mechanical treatment, to one depending almost entirely upon chemical affinity; the carrying out and supervision of which is the task of the metallurgist.

That chemical action shall take place, it is essential that the particles of one or more of the substances to be decomposed or combined be in an easily moveable condition, a state which is secured in two ways:—*Firstly, by producing* fluidity by heat. Secondly, by solution in a menstruum which remains liquid at ordinary temperatures. The first method of treating ores is known as the "*Dry Way,*" the second as the "*Wet Way.*" Both methods are used in the metallurgy of copper; the first chiefly where copper alone or copper and some of the baser metals are the valuable constituents of the ore treated; the second is often employed where silver as well as copper result from the operation, or where iron and copper vitriol are produced. The wet way in the reduction of copper is, however, subordinate to the dry way; and is seldom or never employed alone for the production of fine metal from the raw mineral; it is, nevertheless, very valuable because it enables the metallurgist to take advantage of certain affinities, which cannot be made use of by the other method, to effect a more complete separation of different metals, and also on account of the smaller quantity of fuel required, which, in regions poor in wood, coal, and roads, as in some parts of Spain and Austria, is a matter of primary consideration.

METALLURGIC PROCESSES BY THE DRY WAY.

Roasting.—By this term is understood the heating of an ore or metallurgic product to a degree less than that at which it melts, and generally subjecting it at the same time to the action of an atmosphere of gas, as air, chlorine, or carbonic oxide, for the purpose of bringing about chemical changes. It is evident that the circumstances favourable to this process are fineness of the particles and porosity of the substance subjected to the action of the gases, frequent stirring, by which a fresh *surface* is exposed, and a rapid changing of the gaseous atmosphere, all of which tend towards bringing the particles of the different substances in closer contact with each other.

Four kinds of roasting are distinguished, and they are all more or less employed in the treatment of copper ores. First; *oxidising roasting* is that by which the quantity of oxygen in substances subjected to it, is increased. Second; *reducing roasting,* where the proportion of oxygen is reduced by the operation. Third; *chlorising roasting* has for its object the formation of the chlorides of the various metals. And fourth; *volatilising roasting,* where it is sought to drive out certain volatilisable substances from their combination with the ore, as water or sulphuric acid break. Generally, in practice, two or more of these processes go on at the same time.

Fusion.—Taken in a metallurgic sense, this term designates that process by which a mineral is brought in connection with certain fluxes or re-agents, by means of a greater or less heat to a fluid condition. When in this condition chemical changes generally take place, and the mass, under the influence of gravity, separates into various parts, the heaviest constituent being below and the lightest above. Several species of fusion are distinguished by the nature of the changes that are produced.

First.—When substances having different degrees of attraction for oxygen are melted in contact with an oxidising body, as atmospheric air, those having the greatest affinity for that element are combined, and generally separate from those less easily attacked in the form of gases or slag. This is called *oxidising fusion,* an excellent example of which may be studied in the first process in the operation known as refining in the Welsh method of smelting copper ores. Here, over the surface of a melted compound where copper may be accompanied by lead, iron, cobalt, antimony, arsenic, and sulphur, a stream of air is allowed to pass; a scoria formed of the oxides and sub-oxides of all of these metals that may be present, collects and is scraped off, while by far the greater part of the copper remains in a nearly pure state.

When the object of fusion is to subject either natural or artificial compounds of metal and oxygen to the action of some substance having a very great affinity for oxygen, as carbon or hydrogen, for the purpose of allowing the oxygen to be taken away and producing an uncombined metal, the operation is known as a *reducing fusion.* An example of this will be found by referring to the *poling* process in refining copper. Here the melted metal is saturated with the suboxide of copper; the green wood which is introduced decomposes into carbonic oxide, carburetted hydrogens, and other substances capable of forming gaseous compounds with the oxygen of the suboxide, which, passing off, leave the metal in a comparatively pure condition.

When two bodies, being brought to a fluid condition, act upon each other so that a part or the whole of one produces with a part or the whole of the other a new compound, either valuable in itself or, as is more generally the case, which on account of its different melting point or specific gravity can be separated from the substances with which it is mingled, such process is called *dissolving fusion.* An instance of this kind of fusion is furnished by the old process of liquation, once much employed for the separation of silver from copper; copper, holding silver, is melted with lead, the lead *dissolves* the silver, and by a subsequent operation hereafter to be described, the argentiferous lead is drained from the compound.

Precipitating fusion, takes place when an element of a melted compound is separated or thrown down by the addition of a second body; the term is generally used to designate the decomposition of sulphides by means of iron.

In practice, two or more of the above-defined varieties of fusion may go on together, and frequently the occurrence of one, necessitates the occurrence of the other; thus, in the example just mentioned of the *reduction* of the suboxide of copper in the process of *poling* the gases are at the same time *oxidised.* In such case the name is drawn from the nature of the change which the element undergoes that is the chief object of the metallurgic process. The distinctions are mainly valuable in assisting the student to unravel the complicated series of re-actions that go on within the walls of a smelting furnace.

Liquation is employed for separating the constituents of a mixture made up of substances with different melting temperatures, by applying a gradual heat to the mass, and allowing the easiest fusible constituent to drain or filter from the more refractory. It cannot be used for dividing chemically combined substances, and at best produces only a partial separation. For these reasons it is gradually being superseded by recent and more perfect plans. Its most usual application is to the separation of silver from copper; three parts of *copper holding* a small per centage of silver are melted with eleven parts of lead, and the compound allowed to cool gradually; a greater part of the lead forms an alloy with the silver, which remains mechanically mingled with the copper, and when subsequently the mass is cast into disks which are placed on their edges upon a peculiarly shaped hearth, and subjected to a heat slightly above that necessary to fuse lead, the alloy of lead and silver filters out, leaving behind a porous mass of impure copper. Both of these compounds must then be treated to obtain their three constituents in a purified condition.

METALLURGIC PROCESSES BY THE WET WAY.

By a metallurgic process by the wet way is understood the bringing about of required changes by solution in some menstruum that remains fluid at ordinary temperatures, which is generally water, or water containing an acid or a salt. The employment of this method has been much extended in modern times, and in the metallurgy of copper it has in several instances taken the place of the dry way, especially in the isolasion of silver when it occurs in small quantities in company with the less valuable metal. Ziervogel's method of separating silver from copper consists in subjecting the ore to an oxidising roasting, dissolving out the sulphate of silver thus formed, with water, and then precipitating the silver in a metallic form with copper. By the process of Augustin a chlorising roasting is performed, and the chloride of silver thus produced is extracted from the mass with which it is mixed by dissolving it in a solution of common salt. The metallic silver is then obtained as above, by precipitation with copper. *Cement Copper* is obtained by precipitating the metal from a natural or artificial solution of its salts by means of iron. These processes will be found treated more at length in a subsequent chapter.

PART II.

CLASSIFICATION OF THE ORES OF COPPER; DETAILS OF THE VARIOUS PROCESSES USED IN THE REDUCTION OF COPPER ORES; SEPARATION OF COPPER FROM OTHER METALS; NATURE OF AND MANNER OF MAKING THE ALLOYS OF COPPER; THE WORKING OF COPPER AND MANUFACTURE OF CUPREOUS PRODUCTS; STATISTICS.

CHAPTER IX.

PLAN OF DESCRIPTION; GENERAL PRINCIPLES; METALLURGIC DIVISION OF ORES.

In describing the numerous and various processes that have been contrived for reducing copper from its ores, the plan that recommends itself for its simplicity and completeness, is to select from the chief copper-producing lands of the world several characteristic methods, and consider the processes peculiar to each in detail, and successively from the earliest heating of the mineral to the casting of the saleable product. Thus the chemical re-action peculiar to each variety of ore may be included, and no essential apparatus or operation be left unmentioned. The following have been chosen as best adapted for securing the objects in view :

I. THE SMELTING OF COPPER ORES IN WALES; THE ENGLISH METHOD.
II. THE SMELTING OF COPPER ORES IN MANSFELD, PRUSSIA; THE CONTINENTAL METHOD.
III. THE SMELTING OF NATIVE COPPER AT DETROIT, IN THE UNITED STATES.

The first is in use for reducing the vast quantities of ores varying in composition and richness, which are imported into South Wales. No other system equals it in securing a regularity of production where the changes of the per-centage of metal, and the chemical composition of the mineral are so sudden and unexpected.

The second gives a representation of the processes in use in the furnaces on the continent, where as a rule the ore, being the product of a limited region, suffers very little change in its nature from year to year; and, since the admirable method of Ziervogel for separating silver and copper was invented and is brought to its greatest perfection at Mansfeld, a description of the various operations of which it is composed will be found in their proper place in this chapter.

The third example illustrates the method employed for separating the native copper from its mixture of veinstone, as practised with the minerals of Lake Superior.

GENERAL PRINCIPLES OF COPPER SMELTING.

One or all of the following peculiarities of copper lie at the foundation of most of the methods which are in use for purifying it by the aid of fire:—1st, its attraction for sulphur is greater than that of any of the metals with which it is found in combination, as iron, lead, nickel, cobalt, zinc, arsenic, antimony. 2nd, its affinity for oxygen is very small, less than that of any other metal likely to occur with it, except gold and silver. The metallurgist, by allowing it to combine or remain in combination with the sulphur usually present in its ores, has a comparatively fusible compound, which on account of its fluidity or peculiar specific gravity, can readily be separated from many of its less fusible, and lighter or heavier, impurities. By roasting his furnace products, he gets rid of sulphur which would be troublesome in subsequent operations, and by subjecting the fused metal while in an impure state to the action of oxidising agents, as the atmosphere, he brings about combinations in the adulterating substances without the copper being materially attacked.

METALLURGIC CLASSIFICATION OF THE ORES OF COPPER.

For the purposes of the smelter all the compounds from which copper is obtained may be arranged under three heads.

1. *Native or uncombined copper.* This is principally found on the Ural, on the borders of Lake Superior and in South America. The latter country sends much of this copper to Europe to be purified. It occurs generally in small grains, and is mingled with red oxide, malachite, pyrites, and earthy gangue; it usually contains only traces of arsenic and is otherwise very pure, producing 60, 70, and even 90 per cent. of metal. The Lake Superior mines produce three sorts: 1. *Mass Copper*, which consists of vast blocks, weighing as high as 8000 or 9000 lbs., and containing only a small quantity of silver, and a few nodules of earthy veinstone as impurities. 2. *Stamp work*, or small pieces of copper which have been cleaned of their gangue by the stamps; and 3. *Barrel work*, which is the result of washing the powder coming from the stamps, and contains from 45 to 60 per cent. of metal.

II. *Oxidised ore.* Except in Australia this kind of ore is found in comparatively small quantities, and at a limited number of localities. This division includes *Black oxide of copper,* which is a product of the decomposition of other ores, and usually is accompanied by manganese and iron. *Atacamite* which contains from 45 to 50 per cent. of a very pure copper; the *carbonates of copper* which occur in Australia, Africa, and the Ural, and various other localities. They are generally pure and give good copper; but when formed by the decomposition of other minerals, they have always a small quantity of adulteration. *Silicates* are found in the Ural, and in South America; they are easily reduced, and furnish a pure copper.

III. *Ores containing Sulphur, Arsenic, and Antimony.* From these compounds by far the largest part of the copper brought into commerce is won. They are the most difficult to reduce, and require numerous and complicated processes to carry off their many impurities. In the ores containing arsenic and antimony, silver is a frequent and valuable constituent. *Copper Pyrites:* this is the most common ore of the metal; it is found generally in company with quartz, calcspar, heavy spar, carbonate of iron, and the sulphides of iron, zinc, and arsenic. When entirely pure it contains 34 per cent. of copper, but on account of the adulterations, which it is impossible to separate entirely by the most careful washing, it generally comes to the furnace holding from 8 to 15 per cent. At Fahlun in Sweden, where this ore is worked, the average richness is from 2 to 3 per cent.; at Rörass in Sweden, 5 per cent. *Variegated copper ore* contains when pure about 55 per cent. copper, and *is not very* widely distributed. *Sulphate of copper* comes in small quantities from South America, where it was evidently formed from the decomposition of other ores. The waters of various mines contain this salt in solution; it is then won by the process of cementation, and produces a copper which depends for its excellence upon the absence from the solution of arsenic and antimony. *Gray copper ores* contain arsenic and antimony, and occasionally so much silver that that metal is the most valuable of their products. These ores are found in but a few localities, and on account of their disposition to crush easily to a fine powder, cannot be concentrated by washing without much loss. Their proper management, to obtain the copper and silver separate and sufficiently pure, is one of the most difficult problems set before the metallurgist. The phosphates and arseniates of copper are widely disseminated ores, but are not much worked; a small quantity of the latter reaches Swansea from Chili, and produces from 30 to 35 per cent. of metal.

CHAPTER X.

THE SMELTING OF COPPER ORES IN WALES; THE ENGLISH METHOD.

THE plan of reducing copper from its ores which is known distinctively as the "English Method," and which is to be found in use, more or less modified, in nearly all the countries where Anglo-Saxon energy has planted smelting works,—in the United States, in the South Sea islands, even in central Germany,—seems to have originated in essentially its present form near where it is now to be found employed in smelting nearly half the copper produced upon the globe,—on the southern shore of Wales.

The distinguishing and most obvious peculiarity of this method lies in the use of reverberatory furnaces to the exclusion of all others, in carrying out its various processes, and in the fact that the sulphur of the ore is made a chief reducing agent, instead of the coal and carbonic oxide which play the same part in the cupola furnaces, the action of which is yet to be described. It further differs from the usual continental method in the last operation, the blister copper being here purified and made malleable in the same fusion, and the product sent to market in the form of bars or ingots ready to be wrought directly; while the continental furnaces generally produce, as their merchantable product, what is known as *rosette copper*,—thin disks of metal holding so much suboxide that they break readily with a short red fracture, and must be subjected to a subsequent refining before they can be hammered or rolled.

COMPOSITION, ORIGIN, AND MIXING OF ORES.

The English method is adapted to the reduction of all classes of ores. It is used in smelting the products of the mines of every quarter of the globe,—the rich sulphides of Cuba, Chili, and New Zealand, the poorer sulphides of Cornwall, and the valuable oxides and silicates of Australia.

The following table will give an idea of the composition of some of the most abundant of the ores that are brought to the Swansea smelting works :—

Name of Mine.	Copper.	Iron.	Sulphur.	Silica.
Cornwall.				
Tincroft	7·5	33·0	13·5	30·4
Great St. George	6·3	20·7	16·0	48·2
East Crofty	6·9	31·0	12·5	33·7
Fowey Consols	14·1	31·8	17·6	23·1
Dolcoath	10·0	32·0	15·3	26·6
Great Work	14·1	18·9	14·0	43·5
Ireland.				
Knockmahon	8·3	19·7	14·2	57·6
Casheen	17·5	12·3	10·2	58·7
Anglesea.				
Parry's Mine	22·0	27·2	28·0	20·8
Cuba.				
Cobre	23·2	30·4	20·8	19·6
Cobre rough ore	19·3	18·3	20·7	40·1
Chili.				
Copiapo	26·3	22·4	19·9	19·3
New Zealand.	12·7	33·9	35·1	18·3
Australia.				
Burra Burra	39·4	12·4	0·0	20·0
,, ,,	22·0	33·7	0·0	23·2
Princess Royal	32·0	19·5	0·0	22·0
Kapuda	16·0	8·0	0·0	60·0
Molong	28·6	4·0	19·3	49·0

But besides these ingredients there is generally present a variable quantity of tin, antimony, arsenic, iron, nickel, cobalt, manganese, or silver, with alumina, magnesia, or lime.

The classifying and mixing of these ores ready for smelting is a subject of the utmost importance, affecting the cost, quality, and quantity of the metal produced by the subsequent operations. It is evidently a chemical problem, and its proper solution can only rest on analyses and a knowledge of the action of the various bodies present, when brought by fire to a fluid state. It has been shown that the following conditions are to be sought for in making up a working mixture of ores*:—

1st. The copper must not be under 9, nor over 13 per cent.; if under the former it is unprofitably poor; if over the latter, the slags have a tendency to contain copper, creating a loss.

2nd. The mixture, after undergoing an ordinary calcination, should fuse easily without the necessity of adding flux, giving a clean and easily fused slag.

3rd. The matt, or coarse metal obtained from the first fusion shall contain, as nearly as possible, 30 per cent. of copper.

4th. The impurities which will make the quality of the copper lower than that determined upon should be rejected.

In forming this working mixture the rich oxides and carbonates are not used, but are retained to be brought in after the reduction is partly completed.

The average composition of all the ores smelted at one of the Swansea works during a considerable period was as follows:—

Silica	38·5
Alumina	2·4
Lime	0·3
Magnesia	0·4
Copper	13·5
Iron	19·7
Other metals	0·9

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* *J. Napier, F.C.S.,* "Phil. Mag. and Journ. of Science," vol. iv.

Sulphur	23·1
Carbonic acid—oxygen and water	1·2
	100·0

But in considering the reactions which take place as we follow the various processes, we may regard chiefly four of these substances, and consider the ore made up of

Copper	13 per cent.
Iron	29 ,,
Sulphur	24 ,,
Silica	34 ,,
	100

PRELIMINARY OUTLINE OF THE ORDER AND NATURE OF THE PROCESSES CONSTITUTING THE ENGLISH METHOD.

In studying the English method of copper smelting, six distinct processes may be distinguished. These are separated from one another by the charge or mineral being transferred at the end of each from one furnace to another, and by the difference in the nature of the products resulting from each. They are as follows:—

I. CALCINATION OF THE MIXED ORES; a portion of the sulphur and other volatile ingredients are driven off, and some of the iron which becomes dispossessed of its sulphur is oxidised.

II. FUSION OF ROASTED ORES FOR COARSE METAL. The roasted ores and the carbonates and slags which are mixed with them, being melted, yield two products. 1st. Slag to the amount of 65 per cent. of the whole charge, about 88 per cent. of which is thrown away as *being too poor* in metal to pay for remelting, and the remainder returned to the furnace. 2nd. ***Matt*** or *coarse metal*, to the amount of about 35 per cent. which contains about 30 per cent. of copper, and after granulation goes to process III.

III. CALCINATION OF GRANULATED COARSE METAL. The process resembles No. I. Much sulphur and some of the other impurities are driven off as gas, and the iron and copper present become partly oxidised.

IV. FUSING THE CALCINED COARSE METAL. The result of operation III., together with slags from operation V., mixed with foreign carbonates or oxides, being melted, produce two products. 1st. *Sharp slags*, constituting about 25 per cent. of the fall from the furnace, and holding 1 to 2 per cent. of copper. 2nd. A matt called *blue* or *fine metal*, containing about 60 per cent. of copper, and being about 75 per cent. of the fall from the furnace; this goes to process V.

V. ROASTING THE BLUE OR FINE METAL. The matt produced by process IV. is freed, during this operation, of much of its iron, silica, and sulphur; here, also, the products are two. 1st. Slag or scoria, amounting to 33 per cent. of the fall from the furnace, holding about 10 per cent. of copper, and known as *roaster slags;* and, 2nd. *Blister copper*, or *pimpled metal*, of which about 95 per cent. is copper.

REFINING THE BLISTER COPPER AND POLING. The iron, nickel, cobalt, zinc, sulphur, &c., are oxidised and removed, and the suboxide of copper which dissolves in the metal reduced.—Result, malleable, tenacious, and merchantable copper.

PROCESS I.—CALCINATION OF THE MIXED ORES.

The object sought to be accomplished by this process is to drive off the water and the volatile arsenic, antimony, and all of the sulphur that is not required to form a sulphide or matt, which shall amount to 35 per cent. of the product of the next following fusion; and further, to form from the sulphide of iron, oxides that will combine readily with the silica of the ore to form a slag. The operation is performed in what is known as the calcining furnace or *calciner*, which is a large reverberatory furnace, having the form shown in the accompanying drawing, in which one corner is represented as cut away that the interior arrangement may be better seen. The size of this apparatus varies: the *hearth*, S, is usually 16 feet long, and 13½ feet broad; it is formed of refractory bricks set on edge, and *firmly imbedded* in fire-clay. The fire-brick arch,

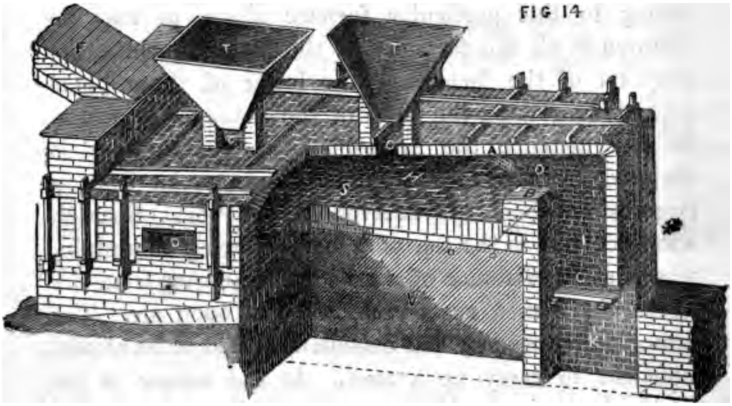

FIG 14

A, descends rapidly towards the hearth as it approaches the *flue*, F, and it is perforated with two holes, C, C, which are capable of being closed tightly. Each side of the furnace is supplied with two doors, of which one is shown at D, and through these the workman stirs the charge, and watches the progress of the work. In the hearth, and represented by V, are apertures leading into the vaults or *cubs*, V, that lie beneath the furnace, and serve to receive the ore, which, when ready, is scraped into them. Above the furnace are placed two iron hoppers, T T, into which the ore is thrown before being dropped upon the hearth. The flue, F, carries the vapours off to a *stack* or chimney, which may belong to this particular furnace alone, or may be common to all the furnaces of the establishment: the adoption of the former or the latter of these plans depends largely on the fancy of the manager or owner. In one instance the necessity of a tall chimney is obviated by carrying the fumes and smoke from a large establishment (Cwm Avon Copper Works) through a long culvert to the top of a neighbouring mountain, where, at the distance of a mile and a quarter from the works, the heated gases rush into the open air. The draught produced by this expedient is said to be almost sufficient to carry up a man. At the corner of the *fire-bridge*, B, is an opening, O, which is arranged with a damper, so that it may be opened or closed at the will of the workman, and air is thus allowed to flow over the heated ore in the hearth, S. The deep-set grate-bars, P, rest loosely in their places, and support the coal which consumes in the fire-place, I. All parts of the furnace that are exposed to great heat are formed of *fire-brick; the* exterior walls are of the usual red brick, and the whole structure is bound or *cramped* with wrought iron rods, that are passed through the walls in various directions, and are keyed on the exterior to cast-iron *bearing-plates.*

Instead of this single furnace, some establishments are provided with calciners having two, and even three, hearths, one above the other, which are used under the impression that an economy of fuel is thus obtained; others have the ore calciner on the top of the smelting furnace; while a third plan is to connect the calcining hearth with the smelting hearth upon the same level, and heat them both with the same fire.

The fuel used in the furnaces of Swansea is, as has already been shown, the mineral coals of the Welsh basin. The deep fire-place is especially contrived to secure their proper burning, and to enable the workman to make use of the support of clinker, which forms from the semi-fused ash. The workmen are able to regulate the draught and manage the fire from beneath, and the unconsumed results of combustion fall into the commodious ash-pit, K.

The mixture of ores having been satisfactorily made, is carried to the large hoppers, T T, and at the proper time let down upon the hearth, where it is spread equally over the fire-brick surface, covering it to the depth of 6 or 8 inches. The quantity of ore put in varies, according to the size of the furnace, from three to six tons. The fire is in the beginning kept low, and the first hour or two serves to heat the charge gradually without bringing about important chemical changes. It is occasionally moved with a long rake, known as a *stirring rubble,* that is introduced from the side doors, *and serves to* expose a new surface to the action of the fire and air. The heat is gradually increased, so that, at the end of about three hours, the charge is visibly red, and afterwards yellow-red; but since this high heat penetrates only to about one inch below the surface, the ore must be often turned over by means of long iron paddles, that no part may escape the action of the hot gases. The aperture, o, at the corner of the fire-bridge, is left open to an extent deemed necessary for supplying the required quantity of air to secure a proper oxidation, and the draught rushing in at the hottest part of the hearth is rapidly spread over the whole surface.

It is evident from the object sought to be accomplished by this roasting, that the length of time necessary to calcine the ore does not depend upon the amount of copper, but upon the amount of sulphur it contains. The usual time is somewhat over nine hours, and when the ores are especially rich in sulphur and silica, even as much as twelve hours are needed.

In those furnaces where the ore is calcined on two hearths, the charge to the amount of about four tons is first put on the top of the furnace, where, after becoming dry, it is passed to the upper hearth by apertures in the arch. This hearth is heated from below, and serves to bring the ore to a condition that fits it for rapidly calcining after being passed to the lower hearth. After remaining here for about six hours, and being subjected to a strong fire, it is ready for taking out.

In either furnace, when the ore is sufficiently calcined, it is scraped through openings into the vaults or *cubs below,* where it is completely drenched with water, in *which operation much* sulphuretted hydrogen is given off, and a corresponding quantity of oxides formed. The ore is then removed from the cubs to a yard, where it is allowed to remain stored for some time, since it is found that the decompositions which take place in the damp powder aid in securing in the next smelting a matt richer than that obtained when the ores are fused directly from the calciner.

The chemical changes which take place in a calcining furnace are extremely simple when pure ores are present. As the heat rises, some of the sulphur of the iron pyrites volatilises, and then sulphurous acid and the oxides and sulphates of some of the metals are formed. When at the end of the process the temperature is raised very high, most of these sulphates are decomposed, and the oxides remain behind. When antimony and arsenic are present in the ores the action is somewhat more complicated. During the earlier part of the operation, when the sulphur goes off, the two metals accompany it to a small extent as sulphides. When the heat is raised a little higher, and but a small amount of air is admitted, the oxide of antimony and arsenious acid are formed, both of which being volatile are carried off through the chimney. But when the heat is still further increased and more air admitted, these two substances take on more oxygen, and combine with the bases present, forming refractory antimoniates and arseniates, which remain with the mineral. In cases where the establishment has sufficient ore for the purpose, those holding arsenic and antimony are calcined alone, and slowly, until nearly all of those disadvantageous substances are driven off, and then mixed with the purer pyritiferous ores which supply the sulphur necessary for making a matt.

Hence a large establishment, supplied from a great number of localities, is often enabled to make excellent copper from ores of but moderate purity. The tin that may be in the original mineral cannot be removed by calcining. About 1 cwt. of coal will be required to calcine a ton of ore, and at the end of the process from 12 to 15 per cent. of sulphur will still remain in the charge. In calcining, three men are employed to attend each furnace by day, and three by night; they are paid by the watch, and but little skill is required to carry out the process.

PROCESS II.—FUSION OF THE ROASTED ORES FOR COARSE METAL.

The object of this operation is to concentrate the copper in a sulphide or matt, and remove from the roasted ores the silica and earthy matters with which they are encumbered. The furnace in which the process is performed is represented in the adjoining drawing. A large furnace of this class has a hearth, C, 14 feet long by 11 feet broad, and measures on the exterior of its walls 22½ feet by 15. All the parts exposed to the fire are built of the best fire-brick, of which 8500 will be required in its construction. The grate, E, and the fireplace, F, are arranged for burning coal in a clinker-bed, and their dimensions are made to bear a proper proportion to the area of the hearth, C. The workmen can descend into the ashpit, A, to regulate the fire, and at the opposite end of the apparatus the door, D, is used for drawing the melted slags from the hearth. A hopper, H, on the top of the furnace serves to collect the ore previous to letting it down upon the hearth, C, and a hole in the lowermost part of this hearth, furnishes a means of tapping off the melted matt that collects during the smelting.

The construction of the bottoms, B B, requires much care on the part of the furnace-man; the material of which they are made has already been spoken of in Chapter VIII. It is a highly silicious sand, and is usually obtained from the sea shore, where it has undergone a process of winnowing by the winds, so that much of the lime that originally existed in it in the form of small shells has been carried away. Two inches of slags are first melted on the floor of the newly made vault; sand is thrown upon this to the depth of about 18 inches, calcined for a couple of hours and then shaped and beaten down; some slag is then thrown in and melted on the surface; a second layer of sand 4 inches deep follows, and above this a thin layer of slag; the whole being subjected to *repeated meltings* is ready for use. These bottoms

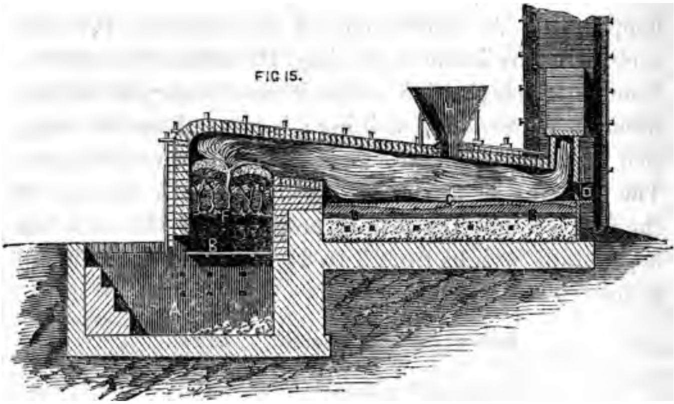

FIG 15.

will sometimes last 12 months, but are generally not so durable; they absorb a considerable quantity of copper, which is thus locked up as dead capital, and by their gradual melting out, they supply the ore with an important silicious flux.

The roasted ore from the yard is weighed out in hundredweights, and carried by the workmen to the hopper, H. At this stage of the process, the raw carbonates are introduced, since the absence of sulphur from their composition makes it unnecessary to subject them to a previous calcining; besides these the slags, rich in copper from process IV., are here worked over. The amount of the charge will vary with the size of the furnace, and the fusible properties of the ores, but it generally weighs from 3 to 3½ tons, and is made up as follows:—

Calcined ore from process I. ...	36 cwt.
Raw ore	26 ,,
Sharp slag from process IV. ...	8 ,,
	70

To this, when a fluid slag is sought, silica and fluor spar are added. The charge is precipitated into the furnace by drawing a slide from the bottom of the hopper, and is spread evenly over the hearth. The doors are closed, the air holes stopped with clay, and the heat raised as rapidly as possible. Through small apertures in the door and chimney, the workman watches the condition of the interior, and regulates his draught and fire accordingly. At the end of five hours when the furnace has reached a white heat, and all appearances are favourable, the door is removed and a long rake passed through the fluid contents, to see if the whole charge is perfectly fused. This being the case, the workman after allowing the mass to settle, begins the operation of *skimming*, that is, drawing off the scoriæ or slag, which has formed, and from its low specific gravity floats on the surface of the matt; this is done by means of a long scraper, the slag being removed through the aperture, D. Much experience is required in properly conducting this operation, and great care is necessary in drawing the scraper along the surface of the metal, so as not to take out any of the valuable lower stratum along with the slag. When the workman by a want of attention allows copper to mix with the slags, so that they hold more than about a quarter of a per cent., he is compelled to resmelt them free of charge; a regulation that serves as a check to secure his good working. When the furnace is skimmed, it is the usual plan to let down a second charge of ore, and fuse and skim in the same manner as above, before tapping the hearth to let out the matt. When sufficient metal is collected, the tapping is accomplished by breaking out the clay stopper, and thus opening a communication between the lower part of the hearth and the exterior. From this aperture the matt is run directly into a vat of water 6 or 8 feet deep and 4 to 5 feet square, at the bottom of which is a box with a perforated bottom that receives the granules thus produced, and which may be raised by a crane and the contents removed to the yard to dry ready for the next operation. Another plan is to run the matt into moulds, and thus form pigs, which are stamped to a powder before going to process III.

Since at the time of throwing the ore into the *furnace the* hearth is at a high heat, smelting soon sets in; the sulphides of iron and copper are formed and sink to the bottom. The silica combined with copper, gives it up to the sulphur, combines with the oxides of iron and other bases, and rises to the top, forming a distinct layer of slag. The tin that may be present goes partly into the slag as an oxide, while the antimony and arsenic combining with the copper are absorbed into the matt. Where insufficient sulphur is present, the copper will not all go into the matt, but a portion will reduce to *blister copper* and fall to the bottom, and at the same time the slag will be found to hold suboxide of copper.

The matt or *coarse metal* produced amounts generally to about 34 per cent. of the charge, and holds about 30 per cent. of copper, 34 per cent of iron, and 30 per cent of sulphur. The slag contains about 70 per cent. of silica, the remainder consisting of various bases; it is broken to pieces and carefully sorted, all pieces containing globules of matt being returned to the furnace again, and the remainder, which is generally not allowed to contain more than quarter of one per cent., is cast away. To produce a clean slag is a primary object with the smelter; and the size of the furnace, the amount of the charge, and the length of time employed for fusion, are all considered as influencing the quantity of metal that remains among the silica.

PROCESS III.—CALCINATION OF THE GRANULATED OR POWDERED COARSE METAL.

The object of this process is the expelling of a large *portion* of the sulphur that forms part of the powdered *coarse metal, the* formation of oxides of copper and iron from the sulphides, and the driving off of as much as possible of the antimony and arsenic. It is performed in a furnace similar in its general features to that used for the calcination of the ores in the first process.

The powdered or granulated matt is transported to hoppers on the top of the furnace, and let down upon the hearth in quantities varying from 3½ to 4 tons. This mass being easily fused, great care is required not to raise the heat of the furnace too high at first, in which case the powder would clot, and, by adhering to the bricks, prove prejudicial to the furnace and to the completeness of the calcination. When a charge is let into a furnace it is first brought slowly to a visible red, and then the fire is cautiously increased until a bright red colour is reached, which should require at least 14 hours. This temperature is continued till the charge has been in the furnace 24 hours, the attendants stirring or turning it over with iron paddles every one or two hours.

The holes leading into the *cubs* are then opened, and the charge scraped through; water is thrown over the powder while it is yet in a heated condition, and when cooled it is carried to a heap to await its transport to process IV.

The chemical changes that take place here are very similar to those described for the first process of calcining. When arsenic and antimony are present it is well to lengthen the action of the fire that they may be carried off, but care must always be taken that 10 or 12 per cent. of sulphur remain in the charge that the next following process may proceed properly.

PROCESS IV.—FUSION OF THE CALCINED COARSE METAL.

The object of this fusion is to carry off a large part of the iron with which the metal is still mixed, and produce a matt which shall be a still richer sulphide of copper. It is carried out in a furnace which differs so slightly from that employed in process II., that it does not require a particular description. At this period again, as at the beginning of process II., the rich foreign carbonates, and those sulphides and oxides containing little iron, can be introduced with profit. The charge of a usual furnace consists of about 52 cwt. and is made up nearly as follows:—

Calcined coarse metal	24 cwt.
Foreign raw ores	24 ,,
Refiner and roaster slag (processes V., VI.)	4 ,,
	52

Beside these substances, copper scales from rolling mills and the *cobbing* or broken hearths are frequently added; and among so many elements it becomes a difficult matter for the furnace-man to know in what proportions he shall make his mixture. The only criterion is deduced from the action of the first charge; hence it sometimes happens that instead of getting as a product, a nearly pure subsulphide of copper, he obtains a matter very largely adulterated with sulphide of iron, and much copper goes over into the slags: failures which must be remedied by a re-arrangement of the proportions of the elements of the charge.

The materials in the proportions above indicated, or in such quantities as the judgment of the furnace-man suggests, are brought on the hearth through the hopper or working door, and spread evenly over its surface. When this is done, the doors are closed and luted, and the fire regulated to give out the required heat. At the end of an hour incipient symptoms of fusion appear as well in the softening of the mass as in the evolution of gaseous matter; and in about three hours after charging, two layers appear on the hearth, the upper thick and undissolved, the lower a thin fluid. The heat is increased and all the solid matter melted; the fused mass occasionally stirred, and the pieces adhering to the sides of the furnace are struck down into the hearth, and at the end of six hours the separation of the charge into two layers appears to be complete. The slags are then skimmed off as in the previous process, and the matt which remains on the hearth, is either tapped off into vats of water and granulated, when it is known as *fine metal;* or the charge is run into sand-beds and moulded into pigs, when it is known as *blue metal.*

In this process the silica of the slags and furnace hearths, absorbs the oxide of iron which has been produced by the roasting; the copper which may be taken up as an oxide by the slag, is removed again by coming in contact with the sulphide of iron that gives up its sulphur to the former metal, which then collects in the matt, or coming in connection with the oxide or silicate of copper, gives metallic copper and sulphurous acid.

The *matt* or *blue metal* obtained, is, when the reactions have been complete, an almost pure subsulphide of copper; but sulphide of iron is always present, and the average composition may be taken at—

Copper	73·0
Iron	6·5
Sulphur	20·5
	100

The slag, which is a proto-silicate of iron with various impurities, contains from 1 to 2 per cent. of copper; and on account of its breaking into sharp edged fragments, is known as *sharp slag*. It goes back to operation II.

PROCESS V.—ROASTING THE BLUE OR FINE METAL.

It is sought by the fifth operation to expel all the sulphur, and to obtain a copper as free as possible from metallic impurities. The means adopted are to expose the matt to the action of heat and the oxygen of the air; and by the addition of a small amount of silica to take up the iron and other oxides as slags.

The furnace is similar to that described for process II.; but is not furnished with a hopper, since the charge, instead of being put in from above, is introduced at a side door. This is done by means of a long paddle, upon which each pig is transported carefully to its proper place on the hearth. The charge amounts usually to 3 to 3½ tons of metal, or enough to produce 2½ to 3 tons of copper. The furnace is much cooled by the introduction of the charge; but as soon as all is in, the door is closed and luted fast, and a strong fire given, so that fusion soon commences. The highly heated gases striking the surface of the pigs causes them to trickle down in drops, in this way exposing much surface to be oxidised, and much sulphur to escape as sulphurous acid. The heat is raised until the contents of the furnace are in a complete state of fusion, in which condition they are kept some time, while sulphurous acid escapes in considerable quantities, causing a boiling in the mass. The fire is now allowed to abate, and the door of the furnace is opened. The result of the entrance of cold air is to cause the formation of a crust on the surface of the fluid, and its reduction from a bright, to an incipient state of redness. The liquid portion beneath, however, still continues to give off sulphurous acid gas, which as it rises in bubbles, causes a motion among the particles that answers the purpose of stirring. The door is closed when the temperature falls too low, and the mass is again brought to a high heat. This smelting and cooling is continued until the gaseous matter ceases to be given off, and the process of oxidation is known to be sufficiently advanced. The door is now tightly closed, and the fire renewed, and increased gradually for six hours, during which time sulphurous acid still continues to escape. Up to this stage, slags, on account of the low temperature, have not begun to form to any amount; but now the fire is raised to its highest point, and the silica which comes from the walls and bed of the furnace, and from the sand that hangs to the pigs, unites with the oxides of iron and copper, and other bases present, and rises to the surface, from which it is carefully skimmed. An impure metallic copper gradually fills the hearth of the furnace; and at the end of the process, which lasts about 24 hours, this is tapped into rectangular moulds formed in the floor of the foundry. This product is known as *coarse copper*, *bed copper*, *pimpled copper*, or *blistered copper*, according to quality; but the term, *coarse copper*, is sometimes applied to all these kinds except the blistered. If the cooling or *setting* of the ingot is accompanied by contraction, it is termed *bed copper*, and other metals, as tin, are then known to be present; when the surface is covered with pimples, which indicate the presence of sulphur, the product is called *pimple copper;* and when the copper is good and ready for refining, it becomes covered with flakes or scales of the oxide, and is then known as *blistered*. The coarse copper contains from 90 to 95 per cent. of metal, and the blistered copper 95 to 98 per cent.; the remainder being in both cases chiefly, iron, sulphur, silica, tin, antimony.

When the pure variety of the metal known as *select copper* is required, a slight change is introduced into the above process. The circumstance that the antimony, arsenic, tin, lead, &c., which exist as sulphides, quickly lose their sulphur, and are changed to a metallic condition, by coming in contact with copper or its oxides, causes these elements to be collected in the first copper that falls as a metal to the bottom of the furnace. When therefore these *copper bottoms* are tapped off—when but about one fourth of the matt is reduced—what remains in the furnace produces a nearly pure metal.

These bottoms sometimes contain as much as 12 to 14 per cent. of tin, and are worked up to form an inferior product known as *tile copper*. The scoria, which is called *roaster slag*, is very basic and rich in copper; it goes back to be reduced in process IV.

PROCESS VI.—REFINING THE BLISTER COPPER AND POLING.

In this process, the smelter brings his metal to the condition of a marketable product. The copper resulting from the last smelting, as has already been shown, contains several per cent. of various substances, such as sulphur, iron, lead, tin, antimony, &c., which it is the object of this operation to remove, and afterwards to produce in the purified copper that condition of malleability which is known as *tough pitch*. The furnace employed is similar to that used in process II., except that it is smaller and has no hole in the hearth through which the contents may be tapped off; instead of this arrangement, the hearth is made to incline slightly toward the front side, where a small depression is left that collects the liquid metal, and allows it to be dipped out with a ladle. The charge, consisting of about eight tons of blister or coarse copper, is deposited in the condition of ingots on the hearth, and the doors immediately closed and luted fast. A strong heat is then given and kept up, until the copper is completely smelted, when the slight slag which collects on the surface of the metal bath is skimmed off, the draught decreased, the apertures prepared for the admission of atmospheric air are opened, and the oxidising process commences. The metal is occasionally stirred with a rake that the separation of the impurities may be more complete; and some refiners throw pieces of green wood on the surface, under the impression that it assists in the escape of the sulphur. The suboxide of copper is formed in the upper stratum of the fused mass, and being soluble by the melted metal is absorbed into it, where meeting with easily oxidisable metals such as iron or zinc, it gives up its oxygen to them; whereupon, by reason of their lower specific gravity, they rise to the surface, and, meeting with silica, they are quickly turned into a slag, which is scraped off by the attendant. Subsequently, sulphur is changed by the same oxidising agent, to sulphurous acid, which ascending to the surface causes a boiling or *rising* in the mass, but the attraction of the tin, arsenic, and antimony for the copper is so great, that but a small quantity of these metals can be extracted in this manner. Some manufacturers add a little lead at this stage of the process, which, combining with a part of the antimony and tin, forms a heavy alloy, that falls to the bottom of the hearth and can be separated. The air is allowed to play over the surface of the metal for some time after the boiling has ceased, until a sample taken from the furnace shows by its colour, fracture, and manner of cooling, that a large quantity of the suboxide of copper remains dissolved, and hence, the refiner being convinced that iron, zinc, and sulphur are expelled, proceeds to the last stage of the process—the *poling.*

The *dry copper,* as the metal having a large quantity of suboxide in solution is called, is first covered with a layer of powdered anthracite or of charcoal, for the purpose of preventing the absorption of more oxygen.

The suboxide that remains dissolved, is now reduced by thrusting within the fluid mass, a large spar or pole of green birch or oak, which is decomposed by the high heat; carbonaceous gases are evolved, which escaping through the metal, act strongly, reducing themselves, and by the commotion produced, cause every part to be brought rapidly and thoroughly in contact with the anthracite or charcoal on the surface, and in this way all the suboxide may soon be reduced to metallic copper, while its gaseous portion escapes in combination with carbon into the air. This action is continued for from a quarter to half an hour, during which time samples are taken at short intervals and tried beneath a hammer or in a vice to determine their malleability. When the metal has reached what is termed the proper *pitch*, the assay bends readily without showing any breaks on the edges, and its fracture should have a fibrous silky lustre, and a light colour. When this pitch is attained, the pole is withdrawn and a larger sample termed a *trial*, taken out, and cast in a small mould, and is beaten with sledge-hammers into a plate. If the copper be good this plate will not crack on the edges, and the surface will be smooth and free from scales. It occasionally happens that poling is continued too long, in which case all the suboxide is reduced, and the metal assumes a light colour, loses its toughness, and becomes hard. To remedy these defects, which are variously ascribed to the absorption of carbon from the pole and coals, and to the action of the impurities in the metal, which the presence of a small quantity of the suboxide of copper neutralises, the air is again allowed to play over the surface in order to oxidise the carbon, or produce more of the suboxide, and the operation of poling repeated. When by the assay and *trial* the copper is found to be neither insufficiently deoxidised [*dry*] nor *over-poled*, but to be of good colour, soft, malleable, and tenacious (*tough pitch*), it is laded from the furnace into moulds which form it into ingots, tiles, or wire-

bars, as the demand may be. When it is intended for the manufacture of brass, it is granulated by a process resembling that described for the granulation of the *coarse metal*. When the water into which it is thrown is hot, round grains are obtained analogous to lead shot, and copper in this state is known as *bean shot*. When the melted metal falls into cold water, the grains are irregular and thin, constituting *feather shot*. Copper is also made into small ingots about six ounces in weight; they are intended for exportation to the East Indies, and are known in commerce as *Japanese Copper*. These little pieces, as soon as solidified, are thrown in their heated condition into cold water, which slightly oxidises their surface, and gives them a fine red colour.

Copper is sampled for sale by drilling two holes on opposite sides of the bar or ingot, and dividing the chips produced between the assayers of the buyer and the seller, from whose analyses the worth of the product is determined.

CHAPTER XI.

THE SMELTING OF THE COPPER ORES IN MANSFELD, PRUSSIA; THE CONTINENTAL METHOD.[*]

THE county of Mansfeld, which lies just beyond the south-west borders of the Hartz, has long been celebrated for its copper. Previous to the thirty years' war, much metal was sent hence to the manufacturing centres of Europe. That convulsion destroyed its prosperity for a time, but about 1730 its mines and furnaces were again opened, and from that period until the present day, copper and silver have been produced in gradually increasing quantities, and new processes of reduction have been successively invented and adopted, and in their turn replaced by better, until, at length, a degree of technical perfection has been attained which leaves little to be desired.

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[*] The descriptions of the Mansfeld process, which even to within a very recent date have been published in the English language, will be found to differ widely from that given here. They generally exhibit the condition of the metallurgic processes as they existed thirty years ago. Since that period no method in copper smelting has passed through a more remark-

able and instructive series of phases. The ancient process of *liquation* (see chapter viii.) was then in use for separating the copper and silver, and the various smeltings and roastings had the object of preparing the metal for this wasteful operation. This ceased entirely in 1836, and gave place to the less expensive but unhealthy method of *amalgamating the copper matt*, which had long been in course of experiment at the company's works. This continued until 1849, when the ingenious process of Augustin was adopted for a time. It was in its turn replaced by the simpler and cheaper plan of Ziervogel, which was invented in 1840, and brought to a limited extent into use in 1844, and has been since 1851 exclusively employed.

The difference in the previous and subsequent working of the copper mineral makes it difficult to institute a comparison of the expense of desilverising by the various plans, but roughly the cost of treating one hundredweight of copper, which usually holds ½ lb. of silver, was by

Liquation...............	10	thalers.
Amalgamation.........	5½	,,
Augustin's method ...	4½	,,
Ziervogel's method ...	2⅓	,,

And the amount of silver remaining in the copper was, by

Liquation...............	$\frac{1}{10}$th of one per cent.
Amalgamation	$\frac{1}{17}$th ,,
Augustin's method...	$\frac{1}{17}$th ,,
Ziervogel's method ...	$\frac{1}{84}$th ,,

I cannot fail here to express my thanks for the kind attentions and assistance given me by the very intelligent officers of the various mines, furnaces, and rolling mills belonging to the Mansfeld Company near *Eisleben, Hettstedt,* and Rothenburg.

The various mines and furnaces which were originally possessed by separate companies, were united in 1852 under a single direction, the chief office of which is situated in Eisleben, and at present an admirable system connects the various mines, furnaces, desilverising works, hammering establishments, and rolling mills, and profitable returns are secured to the stockholders.

The ore occurs in a remarkable bituminous seam or stratum in the Zechstein,—a portion of the group known to English geologists as the Permian, which has already been shown to be distinguished for its richness in copper. It differs from most copper ores in being found not in a regular vein, but stratified like coal or slate, whence is derived its usual name of *copper schist*. Regarding the manner in which these ores were deposited or concentrated, geologists have as yet given no satisfactory theory.

The mining, which is sometimes carried on to the depth of seventy or eighty fathoms, is particularly arduous on account of the diminutive size of the ore-seam, the whole thickness of the stratum taken out seldom amounting to more than eighteen inches, which makes it necessary for the miner to do all his work while lying flat on his left side.

The portion which is smelted, constitutes but from 10 to 18 per cent. of this stratum; and here the copper is chiefly contained as finely disseminated particles of the various sulphides. The following analysis by Berthier gives the constituents with approximate accuracy:—

Silica	40·0	per cent.
Alumina	10·7	,,
Carried forward	50·7	

Brought forward	50·7	per cent.
Oxide of iron	5·0	,,
Carbonate of lime ...	19·5	,,
Carbonate of magnesia	6·5	,,
Potash	2·0	,,
Sulphide of copper ...	6·0	,,
Water and bitumen ...	10·3	,,
	100·0	

The proportion of the silica to the earths is such that the fusion is accomplished with little difficulty—a circumstance of great weight in settling the economy of reduction. The proportion of copper in the ore varies between 2½ and 5, but will average in the neighbourhood of 2¾ of one per cent., and the amount of silver present averages not more than $\frac{1}{70}$th of one per cent., or one pound of silver for 200 lbs. of copper. Besides these metals, zinc, lead, nickel, and cobalt exist in the raw ore in small quantities, and the winning of nickel vitriol is made the subject of a special operation.

Although the company possesses much woodland in the vicinity of the Hartz, it is found more profitable to sell their wood and charcoal, and bring the chief part of their fuel from England, the German coal fields on the Rhine, and various cities where large quantities of gas coke are made. The English coke is considered of the most superior quality, and it reaches the works of the company in considerable quantities by way of Hamburg.

Small bundles of brush wood or bushes answer as fuel for the muffle furnaces, and for calcining or burning, and the brown coal dug in the vicinity supplies a cheap heating material when mixed with other coals for the reverberatory furnace, and other apparatus where a strong flame is required.

As flux, beside the various slags which being too rich to be cast away are returned to the tunnel head, fluor spar is used where the ore is so silicious as to be refractory. It is obtained in larger quantities in the immediate vicinity.

OUTLINE OF THE PROCESSES IN USE FOR REDUCING AND DESILVERISING THE MANSFELD ORES.

In studying the series of processes which lead to the production of the soluble metals the reader will be aided by keeping in mind the following order of succession.

I. The burning of the schist in large heaps to drive off water and bitumen, and produce a mechanical condition favourable for smelting.

II. The first smelting in cupola furnaces, by which the superabundance of silica and earths are removed as worthless clay, and a *coarse metal or matt* is produced containing about 35 per cent. of copper with silver in the form of sulphides.

III. Roasting the *matt* or *coarse metal* in heaps in the open air, for the purpose of driving off the superabundance of sulphur and oxidising the iron.

IV. Concentration of the roasted coarse metal in reverberatory furnaces, and granulation of the same by pouring it into water. The result of this operation is a *fine metal* holding about 65 per cent. of copper and silver, and a rich slag which is sent back to the *first smelting*.

V. Grinding the *granulated fine metal* to a powder.

VI. Roasting the powdered metal until most of the *copper* becomes an insoluble oxide, and all the silver is *changed to a* soluble sulphate.

VII. Disolving out the sulphate of silver with warm water, and precipitating the metal with copper as *cement silver.*

VIII. Mixing the remainder, which contains about 75 per cent. of copper, chiefly in the condition of an oxide, with fluxes and smelting it in a cupola furnace, producing 1st a worthless slag, 2nd a rich matt which is sent back to the furnace, and 3rd a *black* or *coarse copper* containing 98·5 per cent. of that metal.

IX. Refining the coarse copper, which process is either performed in a reverberatory furnace by a method that does not differ materially from that described in chapter X., thus producing a malleable copper at once from the coarse copper, or according to the usual German method, in what is known as the *German hearth,* by which means *rosette copper* is produced. This product is either sold as such, or subjected to a second process of refining upon a somewhat similar hearth, by which it is brought to a malleable condition.

DETAILS OF THE METHOD OF REDUCING AND DESILVERISING THE MANSFELD ORES.

PROCESS I.—BURNING THE ORES.

The object sought to be accomplished by this process is to get rid by volatilisation or combustion of as much as possible of the bitumen, water, arsenic and antimony, and a portion of the sulphur which are present in the fresh ore, and thus to produce a state of division or looseness among the particles, that will make its fusion easier in the process immediately following. To drive off too much sulphur is however disadvantageous; enough must always remain to produce a good coarse metal. The process partakes more of the nature of a burning than of a roasting, and it is generally accomplished in large heaps generally constructed in the immediate vicinity of, and on a higher level than the smelting furnace.

The ore delivered by wagons from the company's mines is weighed and deposited in the burning yard. When a heap is to be formed, a number of bundles of dry brush wood are laid side by side on the pavement where the borders of its foundation are intended to be, thus enclosing a space 2 or 300 feet long, and 30 or 40 broad. Across this space two or three rows of bundles are laid, and another row in the direction of its longest diameter, and where these interior rows cross, 6 or 8 bundles are piled together. The schist is now brought in wheelbarrows, and piled loosely on these faggots until the heap reaches a height varying from 7 to 10 feet. From 300 to 900 tons are then thrown together and set on fire at one side. The fire gradually spreads, the rows of brush wood furnish canals by which air enters the centre of the heap, the piles of wood along the middle line act to a certain extent the part of chimneys, and the entire heap undergoes a slow smouldering combustion. When the schist is heaped while in a moist condition it burns better than when it is used dry, because when the water has evaporated the mass is loose and permeable for the air. Such a condition is brought about most effectually when the heaps are made during cold weather, so that frozen blocks can be piled together and subsequently allowed to thaw gradually. It is also more than probable that water takes an active chemical part in the combustion. When the fire consumes all the bitumen in the schist, it goes out, and the process is ended; this takes place in a greater or less time according to the size of the heap, but seldom in less than 8 or 10 weeks, and sometimes after 3 or 4 months. The schist is changed by the operation from a dark coal-like mass with a silky lustre to a gray ashy substance, which does not in the least resemble a metalliferous body. Sometimes where strong winds prevail for a number of days, the ore smelts together and forms a solid mass that is difficult to break apart, and which losing much of its sulphur in the high heat, has to be mixed with a highly sulphurised ore in the next smelting. That this trouble may be avoided the workmen often shelter the heaps from the storm by boards, or a coating of small coal placed on the side from which the wind blows. The loss in weight by the operation is about 16 per cent., the volume is made $\frac{1}{10}$ less, and about 10 lbs. of wood are used per ton of ore.

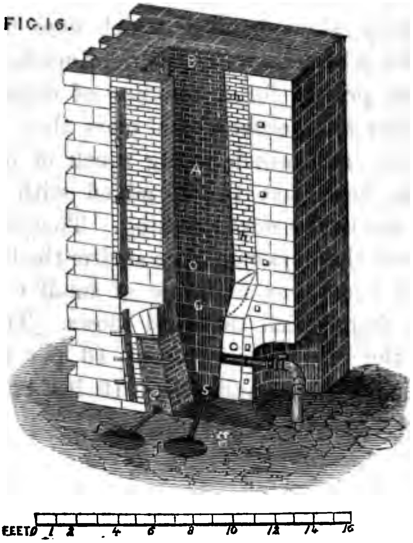
PROCESS II.—THE FIRST SMELTING.

The burnt schist is now carried from the burning yard to the furnace where it undergoes the first smelting. This process has for its object the concentration of the valuable metals in a rich sulphide or coarse metal; and the production of a poor slag which contains most of the silica, lime, and earths, with which the ore is so largely encumbered. It is accomplished in a cupola furnace having the construction shown in the accompanying axinometric drawing (fig. 16), in which one corner is represented as having been cut away, that the interior arrangements may be better seen.

The entire height of this apparatus is 19 feet

6 inches; its greatest width at o, 5 feet 6 inches; the height of the hearth, G, is 4 feet 11 inches; and 2 feet from the bottom at c, are two tuyères of cast iron for the introduction of air. The hearth-stone, s, is 2 feet 6 inches wide, and slopes toward the front side. The lower portion of the furnace where the heat is strongest is built of the red sandstone of the vicinity, which is found to withstand fire very well. The upper portion above o is constructed of fire-brick, and the outer walls are of common masonry. The blast employed is heated to about 370° Fahrenheit, and is forced in with a pressure equivalent to a column of water 7 or 8 inches high. In front of the furnace, hollowed in a *bed of a mixture* of clay and coke powder, are two *basins, ff,* three feet in diameter and one foot deep,

FIG. 16.



into which the slag ore and coarse metal run. A smaller furnace is in use at some of the smelting works, but its similarity to the above is so great that it does not require an especial description.

The materials of the charge to be smelted are transported to a floor near the tunnel-head, B, and consist in general of

86·66	per cent.	roasted ore from operation I.
6·66	,,	Fluorspar.
6·88	,,	Slag from operation IV.
100·00		

The fuel employed is either English and Westphalian coke, or gas coke: when the former is used, 60 to 70 cubic feet are required per 100 cwt. of roasted ore; of the latter, 80 to 90 cubic feet are necessary. This fuel is put on in layers with the ore and flux, and a fresh charge is always added when the gas at the furnace top begins to burn, so that when the operation is proceeding properly, no flame issues from the upper part of the furnace. The contents of the shaft sink gradually towards the tuyères. The metallic oxides in the ore are partly reduced by the carbonic oxide supplied by the fuel; the fluor spar is decomposed, and a volatile compound formed with the silicum; while the lime together with the other bases, as the alumina and magnesia, combine with silica, forming a slag which flows continuously from one of the two openings at H, and hence into the basins, *f f*.

Portions of the zinc and lead are reduced and volatilised, being chiefly blown by the strong blast from behind, in the form of fumes out of the apertures at *e*, producing a long greenish blue flame. The copper, silver, and some of the iron smelt together as a compound sulphide or *coarse metal*, and flow with the slag into the basins, *ff*. By reason of its greater specific gravity, this metal collects at the bottom of the basins, and the slag floats upon its surface. As the hollows fill, the workmen drag away this slag which is tough and glassy, and remains soft for a long time. It is pressed into iron moulds and allowed to cool, after which it is sold to the neighbouring peasants for building stone.

The basins, *ff*, are used alternately; the coarse metal which collects in them is allowed to cool in one, while the other is being filled, an operation requiring from 8 to 12 hours. The cooled mass is drawn from the basin by means of an iron bar which is inserted in it while yet fluid, and broken in pieces with sledges. The rough exterior is sorted out and returned to the fusion just described, while the remainder, being about 10 per cent. of the quantity put into the furnace, and consisting chiefly of copper, iron, silver, nickel, cobalt, and zinc with sulphur—the copper constituting from 30 to 40 per cent., and the silver from $\frac{1}{8}$ to $\frac{1}{4}$ per cent. of the compound—is now passed to a yard near the furnace to undergo the next operation.

PROCESS III.—ROASTING THE COARSE METAL.

This is performed in the open air, in stalls 6 or 8 feet square, and capable of holding 200 to 300 cubic feet of coarse metal and fuel. These stalls are simply open pens of common masonry formed of three permanent walls, and a fourth composed of loose stones which may be taken down when metal is to be introduced or removed, but affords a permeable support for the pile while combustion is going forward. A portion of the metal requires a repetition of the process of roasting. For the first fire, the metal in pieces about a quarter of a pound in weight, is piled in the enclosure upon a layer of wood, that serves to kindle the mass, which when once heated, continues to burn by the consumption of its sulphur. To regulate the admission of air, a layer of breeze or coke powder, about 4 inches thick, is spread over the surface of the heap.

When 20 tons are burned together, the combustion continues about 10 days, and a loss of sulphur and other substances is experienced amounting to 12 or 13 per cent. When a second roasting is required, the small quantity of sulphur present makes a larger amount of fuel necessary. The roasted metal is piled in smaller heaps, and for every 5 tons, 14 cubic feet of charcoal and 400 lbs. of wood are used. This second operation produces a mass rich in the oxides, and of a dark brown cellular appearance, which together with a proper quantity of the product of the first roasting, is now subjected to process IV.

PROCESS IV.—SMELTING FOR CONCENTRATED METAL.

This operation was formerly carried out in a cupola furnace of a construction similar to that described above, but within the last ten years this has been entirely superseded by the English reverberatory smelting furnace, which was introduced by Hüttenmeister Ziervogel from Swansea. A description of this furnace has already been given in the chapter devoted to the consideration of the English method of smelting copper, and the changes that have been introduced at Mansfeld are so unessential, that a further detail is not required.

The object of this smelting is to secure for the subsequent process of desilverising a *matt* or *fine metal* very rich in copper and silver, and to drive off the arsenic, lead and zinc that may be present, and if allowed to remain would interfere with the extraction of the silver, and injure the quality of the copper produced.

The roasted coarse metal is wheeled to a large platform above the furnace, and there mixed as follows :—

12 cwt. of coarse metal twice roasted.

1 or more cwt. of coarse metal once roasted, the quantity depending on the amount of sulphur required.

2 cwt. of slag from process II.

2½ cwt. of quartz in the form of sand.

This mixture is thrown into the hopper on the top of the furnace, and by means of an iron sluice let through an aperture in the vault once every eight or nine hours. The workman spreads the charge over the surface of the hearth with a long iron rake; a strong fire is then made, and smelting sets in. At the end of 7 or 8 hours, the contents of the furnace are in a fluid condition, the silica has combined with the oxide of iron and the earths, and swims upon the surface of a thin stratum of matt, which consists of the sulphides of copper and silver. This slag is scraped off at a side door, and a new charge let down upon the hearth, smelted as before and the slag drawn off. These smeltings require 16 or 17 hours, at the end of which time a large quantity of matt has collected in the bottom of the furnace.

A clay plug is now broken from an aperture in one *side of the hearth*, and the matt allowed to run through a stone spout into a trough containing water, where it separates into small drops or grains and falls to the bottom; when shoveled from this vat and dried, it is ready to be sent to the mill to be ground to a powder. The slag that is drawn from the surface of the matt, contains some copper, and is carried back to process II., where it is mixed with the burnt ore and again smelted. The fuel employed is a mixture of English coal and an earthy brown coal which is found in abundance in the vicinity, in the proportion of 11 of the former to 16 of the latter. By means of an inclined *stair* grate recently introduced, the proportion of the cheaper brown coal that can be used is increased to 24 parts to 11 of English coal.

PROCESS V.—GRINDING THE CONCENTRATED METAL.

The object of grinding is to bring the concentrated metal to the state of a fine powder, that during the next following operation, upon the success of which so much depends, the greatest degree of uniformity may be secured in the chemical combinations that are brought about upon the roasting hearth. The granulated metal is treated nearly as corn in ordinary mills: it is passed through horizontal burrs 4 feet in diameter, made of the granite of the Hartz, and driven by water power. Upon passing through the stones the rough powder is conducted to be bolted, into a hollow cylindrical sieve having 1400 to 1500 apertures to the square inch, and all the powder that will not pass through this is sent back to the hopper to receive a second grinding. The meal produced by this operation *is collected* from the various smaller establishments.

and transported to the Gottesbelohnung furnace, where the extraction of the silver is exclusively performed.

PROCESS VI.—ROASTING THE POWDERED CONCENTRATED METAL.

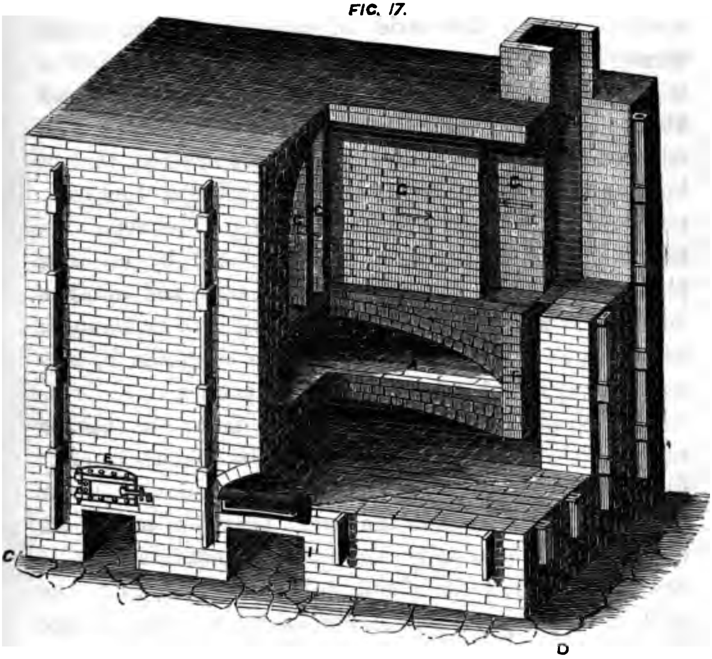
(Ziervogel's method of extracting silver by means of warm water.)

The foregoing operations have constantly tended toward a concentration of copper and silver, which exists disseminated through the poor schists, into a single product. In accomplishing this the attraction possessed by copper for sulphur has been continually taken advantage of, until at this stage of the process a sulphide known as *concentrated metal* is obtained, which in 1860 contained 67·512 per cent. of copper, 0·3521 per cent. of silver, and 6 or 7 per cent. of iron; or to the hundredweight of pure copper 0.5215 pounds of silver were present. This matt is now at the proper degree of richness to subject it to the process of extracting the silver by what is known as *Ziervogel's Method,* and the present roasting is preliminary operation in the extraction.

The essential condition upon which the success of separating the two metals rests, is simply the transformation of the silver as completely as possible into a soluble vitriol or sulphate, while at the same time the copper and other metals are made to take on the condition of insoluble oxides.

This can be done by very carefully roasting the *powdered* concentrated metal or sulphide in furnaces *especially adapted* to the purpose. The construction of these furnaces is shown in the adjoining axinometric drawing, fig. 17. The length of the entire furnace from C to D is 19 feet, its breadth is 13 feet, and its height 15 feet; the two hearths A and B upon which the roasting is performed, are 10 feet long and 8 feet broad, and are formed of good fire brick, which material is also used for the construction of the chimney and all such parts as are much exposed to heat. The fire is made upon the grate through the door E, and the flames passing across a firebridge play over the contents of the hearth B, and going up the flue F, are carried a number of times back and forth through the canals G G, where

FIG. 17.



the small particles of ore that become entangled in the draught are deposited as a very fine powder, and are subsequently collected and carried to the smelting furnace to be fused for the copper and silver they contain. From this series of canals the gases escape through the chimney H into the open air; the hearth A is entirely heated by the flames circulating below and above it, being to all effects a muffle, and hence well adapted for the purpose to which it is devoted, that of heating the mineral before it can be brought to a high temperature, without danger of fusing. Between this hearth and that below, a hole J, closed by an iron plate, permits the shifting of the charge, and another aperture at K allows the finished mineral to be scraped, by means of a long hoe working over the roller U, into an iron waggon that is placed in the vault I.

The powdered matt as brought from the mill, is mixed with about 15 per cent. of the remainder after lixiviation in process VII., and to the amount of 500 or 600 pounds placed upon the upper hearth A, and there exposed to a gradually increasing temperature; this charge is stirred for about 1¼ hours, and then the portion of the powder in the hinder part of the furnace is brought forward near the fire, the small lumps that are formed are broken by beating them with an iron rod and the stirring continued 1¼ hour longer. Then an addition of from 20 to 25 pounds of dry brown coal powder is made to the hot metal, and after 10 minutes stirring the entire charge is scraped through the aperture, and spread equally upon the lower hearth B. The heat is at first allowed to be moderate, but after 1¼ hour stirring, during which the brown coal powder is consumed and a cherry red heat is arrived at, the charge is turned in the furnace and the heat gradually increased.

At the end of 10 or 11 hours from the commencement of the roasting, the workman, who has stirred diligently during the latter part of the period, begins to make his tests for the purpose of determining if the roasting has progressed to the proper point. This is done by drawing from the hearth a spoonful of the hot powder, placing it upon a common saucer, dropping water upon it, and allowing the fluid to filter slowly through. The water takes up the soluble salts that may be in the assay, and from the colour the solution assumes, a good judgment can be formed of the condition of the charge. When slightly blue, but not in the least green, and when a few grains of common salt dropped into the solution throws down a thick white curdy precipitate of chloride of silver, the roasting is considered accomplished, and the charge is drawn out and transported to the magazine. The fuel employed is brushwood, which makes a sharp and easily controllable fire.

In this process the chemical changes that go forward are interesting, important, and complicated. The copper, silver, and iron which exist in the matt as sulphides, act differently when exposed to an oxidising fire. The iron loses its sulphur, becomes a sulphate, and then an oxide, in which state it is insoluble in water: the copper goes through the same series of changes, and the sulphide of silver changes into a sulphate, then into an oxide, and as the heat is continued, into a metallic condition. The operation should, however, not be permitted to continue so long that all these transformations take place.

The skill of the roaster consists in being able to catch the charge just at the moment when the copper chiefly ceases to be a soluble vitriol and has gone over into the form of an oxide, and as much as possible of the silver is in the condition of sulphate, and *before* this unstable salt has been decomposed, and the silver assumed a metallic form. If the roasting is stopped before it has reached this desired point, much copper is left soluble and is carried off in the water, while some of the silver may remain insoluble as a sulphide, and cannot be extracted with water; and on the other hand, if carried a minute too far, metallic silver is formed which, being entirely insoluble in the next process, is left and lost in the copper. Long practice and much observation are required to train workmen for this process, and a scale of premiums have been contrived (see next section), by which good work is rewarded.

The plan of this system of extraction has remained unchanged almost since its earliest adoption, but its value has largely increased within the last few years, an improvement to be traced to the increasing skill of the workmen, who are urged by the hope of reward, to make themselves complete masters of their business.

PROCESS VII.—DISSOLVING THE SULPHATE OF SILVER FROM THE ROASTED CONCENTRATED METAL.

(*Ziervogel's method of extracting silver by means of warm water.*)

The roasted concentrated metal which is now in the *form of* a dark, loose powder, after having cooled *sufficiently in* the magazine, is transported to the department devoted to lixiviation; this is a large room having a series of vessels arranged as in the accompanying drawing.

The wooden vessels, A B C D and E are so placed that the liquor flowing from one may run into the next. A C and D are tubs having double bottoms so arranged

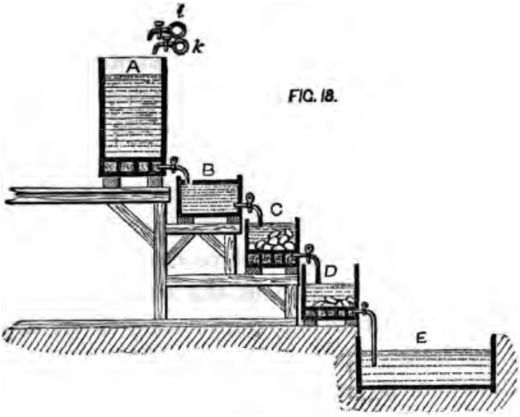


FIG. 18.

with linen-cloth filters that only solutions are allowed to pass from one to the other. The roasted powder is placed, to the amount of 4 cwt. in the tubs A, (of which there are 10), and water and liquor from previous operations heated by steam to about 160° are allowed to flow from the pipes *i* and *k*. This fluid permeates the ore in A, takes up the soluble salts, the most important of which is the sulphate of silver, and carries it, in solution, into the vat B, where it is allowed to settle. From this it flows into the tub C, which is provided with 10 lbs. of granulated copper, and 2½ cwt. of blistered copper bars; here, on account of the electro-negative character of the silver when compared with copper, it is precipitated in a metallic condition as *cement silver*. The fourth series of vessels represented by D, also contain copper, and is simply used as a security against any loss that might occur by all the silver not being precipitated in C. From D, the fluid falls into the wooden vat, E, whence it is raised by steam pressure, to a higher level, heated to 160°, and passed over a new charge which, in the meantime, is introduced into the tub, A. An addition of about 3 cubic feet of fresh water is required for each charge, which is furnished by the pipe *i*, while about 22 cubic feet of liquor are run on through the pipe *k*, and at the same time a small quantity of sulphuric acid is added to prevent the disadvantageous influence of basic salts. About 2½ hours are required to dissolve out the silver from each charge of ore; at the end of this time the contents of the tub are transported to an adjoining room, an assay taken, and a new charge is placed in the tub, which is treated precisely in the manner just described. This assay proves the excellence of the roasting; when 0·036 of one per cent. or less remains in the powder, the work is deemed good, and it passes to operation VIII. When, however, more is found, the powder is sent again to be roasted,—the workmen having to attend it without pay. If less than 0·036 of one per cent. of silver is found present, 12 per cent. of the quantity less than that amount goes to the workman who roasted it. The advantages of this system of premiums have already been spoken of.

All ores are, however, not adapted to this method of separation; when antimony and arsenic are present in large quantities, the insoluble arseniates and antimoniates are formed during roasting, and cannot be extracted by hot water. The plan was tried in the Freiberg silver works, and it was found that, on account of the presence, to a considerable amount, of the two above-named substances, there was invariably—even with the most careful roasting,—about 0·15 of one per cent. of silver that remained in the copper.

The silver falls almost entirely in the tub, c, from which it is taken at proper intervals, and brought to a condition fit for sale. Its most important impurities are sulphate of lime, copper in the form of sulphate and in grains, all of which amount to about 20 per cent. The first two are dissolved out by repeated washings; the last is partly taken out by passing very dilute acid over the finely-divided metal. This is now refined in a peculiarly constructed furnace, where it is brought to a fineness of $\frac{980}{1000}$,—the two per cent. of impurity being copper. This silver is bought by the mint in Berlin; and the copper is not considered disadvantageous, since it is allowed to form a portion of the alloy required for silver coins.

PROCESS VIII.—FUSION FOR BLISTER COPPER.

The remainder from the lixiviation tubs that is shown by careful assays to contain less than 0·036 per cent. of silver, is now ready for making into blister copper. This is done in a cupola furnace constructed essentially on the same plan as that which has already been described for carrying out process II., but differing somewhat in its various dimensions. The lixiviated powder, which contains 70 to 75 per cent. of copper, chiefly as an oxide, and some oxide of iron, is mixed with 8 per cent. of a clay containing 50 to 60 per cent.

of silica, and 40 to 50 per cent. of alumina, worked by hand into balls about 4 inches in diameter, and dried until hard. This admixture of clay has the double purpose of furnishing a source of silica for the slag and the formation of the powder into lumps which will not clog the furnace. On the floor at the tunnel-head an addition of about 9 per cent. of sand, 5 per cent. of pyrites, or gypsum, 10 to 15 per cent. of slag from this, or process IX.; and 1 to 2 per cent. of matt from this process, is made, and the mixture placed in layers on the furnace with the fuel, which consists chiefly of English or gas coke. Cold air is employed, and about 150 cubic feet are forced in per minute, under a pressure of one inch of mercury.

The arsenic that may by chance be present is driven off in the hot upper part of the furnace; a little lower down, the silica of the clay and sand combines with the oxide of iron forming a slag; a greater part of the copper is reduced to a metallic condition, by the chemical action of the carbonic oxide gas, and the sulphur furnished by the gypsum and pyrites, serves to clear the slag of its copper, thus forming a rich matt. These are the three products that run continually from the two openings at the lowermost portion of the furnace, and fall directly into a basin in the *brasque* hearth, where they divide themselves according to their several specific gravities. The slag, which rises to the top, amounts to about 30 per cent. of the entire result of smelting, and is dragged off in disks, allowed to cool, broken and sorted, and the pieces containing matt are returned again to the furnace, while that which analysis shows to contain ½ per cent. of copper or less is thrown away.

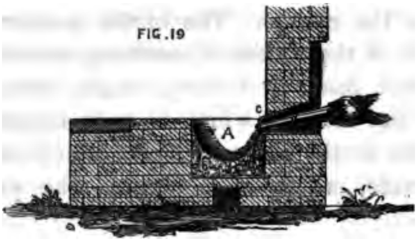
The second product, the rich matt, composes about 5 per cent. of the entire fall from the furnace, and forms a thin layer between the slag and blister copper. It goes back to the tunnel-head immediately, to be mixed with the charge. The blister copper forming 66 per cent. of the results of smelting, collects at the bottom of the basin in a dirty, tough, often cellular mass, 98·5 per cent. of which is pure copper, and is taken thence to the magazine, and afterwards to the Saiger furnace, where it undergoes the process of refining.

PROCESS IX.—PURIFYING AND REFINING THE BLISTER COPPER.

The copper produced by the Mansfeld Works is delivered to manufacturers in two forms: as *rosette copper*, or thin round disks adapted for casting, and the making of alloys, but not sufficiently malleable for hammering or rolling; and as *refined* or *poled copper* which is sold in the form of ingots or bars, and possesses, like the best classes of English copper, the property of malleability in a high degree.

Purifying the blister copper for the formation of rosettes, is a process peculiar to what is known as the continental method. It takes place in an apparatus called the *Small German Hearth*, which has already been mentioned in Chapter VIII. The basin, A, is formed in a mass composed of 1 part sand, 4 parts clay, and 4 parts of charcoal powder, and is large enough to hold 5 cwt. of metal. This amount of blister copper is placed in it and surrounded by charcoal, which is soon brought to a state of rapid combustion by a blast of air that is thrown in through the nozzle, *d*. This nozzle is formed of iron, has an inclination of 10° into the basin, and is 1½ inches in diameter at the mouth. The metal is fused with a moderate quantity of air, then the blast is strengthened, and the impurities such as iron, lead, nickel, cobalt, antimony, and sulphur, being exposed to a strong oxidising influence, are turned into oxides, and can be separated as scoriæ or are driven off in fumes. The copper remaining at the end of the process, which lasts 4½ hours, is nearly pure, except inasmuch as it holds a considerable amount of the sub-oxide which we have seen is largely soluble in the melted metal. When the contents of the hearth are sufficiently oxidised—a condition which is indicated by the depth of the colour of the scoriæ, the colour of the fluid surface, and by the properties of a test taken from the hearth upon the end of an iron bar—the fuel is taken away, and the clean surface of the metal cooled by throwing water upon it. The crust thus formed, which is about 16 to 18 inches in diameter, is taken off by means of a hook, and a second thin disk formed in the same manner. Thus the whole of the metal is removed from the hearth, which may then be repaired for a new charge. These rosettes are considered best

FIG. 19



when they are quite thin, moderately smooth, and of a brilliant red colour; they are now packed in barrels and are ready for market.

From 16 to 17 per cent. of a rich red slag falls by this operation; it holds much nickel which is obtained from it by subsequent processes, some of which are kept secret.

The portion of copper that is refined or brought to what is known in Wales as the "tough pitch," is treated in reverberatory furnaces, and by a plan which so nearly resembles that described in the foregoing chapter that it is not necessary to detail it here.

The long series of years since the beginning of mining in Mansfeld, which have been well used in gathering experience, the unique regularity of the cupreous deposit, and the almost unvarying composition of the ores, have produced in all the operations of the works there in operation a machine-like regularity, which is as extraordinary as it is admirable.

An estimate is made at the beginning of each year of the cost, to the $\frac{1}{10}$ of a farthing, of all the items of expenditure which will be required to produce the fixed number of pounds of copper, silver, lead and nickel, and the result of the year's work seldom shows a notable variation from the determined sum.

The following statistics will give a notion of the importance of the company, and the amount of its business.

In 1858 were directly dependent on the Copper Mining and Smelting Company at Mansfeld;

Persons employed in and about the mines	3697
Smelters, colliers, and machinists	795
Families of the above	7690
Assisted and supported	1375
	13,557

In the same year were raised, 111,920 cwt. of ore at a cost of 79,947*l*., and the following products were sold:—

20,072 cwt. of copper	worth	£113,295	10
13,385 lbs. of fine silver	,,	58,205	10
2,054 cwt. of copper vitriol	,,	506	0
171 cwt. of lead	,,	156	0
13,550 lbs. of nickel Speise	,,	980	0
$2\frac{3}{80}$ lbs. of vanadin	,,	10	0
		173,153	0

CHAPTER XII.

THE SMELTING OF NATIVE COPPER AT DETROIT IN THE UNITED STATES.

THE process of mining and dressing the native copper which is found on the southern shore of Lake Superior, in the United States, has already been described in Chapter V. This product in its various forms as *mass copper, barrel work* or *stamp work,* is transported by lake, river, and railway to Detroit, Cleaveland, and Pittsburg, to be smelted. The advantage secured by this transport, is found in the circumstance that the metal can be reduced in the immediate vicinity of the vast coal deposits of Ohio and Pennsylvania, and fuel can hence be obtained at the works in large quantities at a low price. Within a short time past, however, an establishment has been put in operation in the copper region, on the site of an old furnace near the Bruce mine. It is supplied with fuel, brought as a return load by vessels that carry ore and metal down into the coal regions near Lake Erie. Beside these there are three furnaces in the Union, located respectively at Baltimore, Boston and New Haven, that smelt the produce of the Lake Superior as well as other domestic mines, and also import ores from South America, the Pacific islands, and other parts of the world.

The establishment at Baltimore is operated upon a system not suffering very widely from that already familiar to the reader as the *English method.* The buildings are situated upon the shore of the commodious harbour, and beside ores produced in the neighbouring states, large quantities are brought in by homeward-bound vessels from copper regions in the southern hemisphere. The fuel used is mined in the coal fields of the Alleghanys, and the amount of saleable metal produced annually is given at 4000 tons.

The ores reduced at Boston are obtained partly from mines in New York and the Eastern States, and largely, as is the case at Baltimore, from ports on the Pacific Ocean, whence they are brought by returning vessels as ballast, and delivered at the furnace at prices often quite favourable for the smelter. The nature of these ores is as various as that of those sold at the ticketings in Swansea; the carbonates, the sulphides, the silicate and arseniates are abundant; but the gray copper ores are rare. The quantity of ore smelted in 1854 was somewhat over 10,000 tons, the amount of metal in which, averaged 20 per cent. The system of smelting is somewhat similar to that known as the *continental* *method,* and consists of a roasting, as at Mansfeld, in the open air, and fusion in low cupola furnaces, combined with a subsequent refining in a reverberatory furnace, as is the custom at Swansea. The results arrived at by this scheme of reduction, when considered in an economical point of view, are deemed by Rivot to be exceedingly favourable.

THE SMELTING WORKS AT DETROIT.

This establishment is favourably situated upon the short river connecting Lake Huron with Lake Erie.* Its wharves are accessible to the steam and sail vessels that navigate those waters; and the heavy native ores shipped from the mines of northern Michigan, can be unloaded in the immediate vicinity of the furnaces where they are to be fused. The coal used as fuel, and the most important furnace materials, are transported from Ohio and Pennsylvania by the same cheap means of conveyance, and the copper produced has a convenient outlet to New York, Boston, and Philadelphia, by way of lake, canal, and railway. The ores that are smelted are the property of various mines, and are simply brought to the condition of marketable copper by the establishment in consideration of a certain sum per ton, an arrangement which makes it necessary that the mineral owned by the various mines be kept apart during the course of metallurgic operations.

The three classes of ores have already been stated to to be *mass copper, barrel work,* and *stamp work.* The first generally contains many fragments or nodules of vein-stone that fill irregularities in the exterior of the block or are entirely embedded in the solid metal. It is evident that on account of these peculiarities no accurate assay of the ore can be made, and the result on the smelters books is, in fact, the only criterion by which the per-centage of metal in the blocks can be ascertained. The second class is often almost free from foreign admixtures, but it does not come in such large quantities as the first, while the *stamp work* is often contaminated to the amount of 50 per cent. with quartz, chlorite, trap, carbonate of lime, &c. The severity of the winter causes navigation to be so obstructed that ore can only be transported during the season between May and December; and hence in the winter, smelting ceases, furnaces are repaired, and preparations are made for the operations of the succeeding season.

DETAILS OF THE PROCESS.

The pure character of the ores produced by the Lake Superior mines allows the application of an extremely simple system of reduction, which may be conveniently divided into two processes:—

I. *Fusion of the native metal in reverberatory furnaces,* producing, 1st, rich slags which pass to process II., and 2nd, a copper that is purified and refined in the same furnace in which it is first smelted, and when ready is cast into ingots suitable for sale.

II. The *Fusion of rich slags in cupola furnaces* producing 1st, a poor slag that is cast away, and 2nd, a coarse copper rich in iron, which goes back to process I. to be purified.

PROCESS I.—FUSION OF THE NATIVE METAL IN REVERBERATORY FURNACES.

The furnace here in use resembles somewhat that represented by fig. 15. The hearth is about 14 feet long and 10 feet broad, nearly elliptical in form, and having a slight inclination toward the tapping door near which is a depression where the fused metal collects. This hearth is very thick and solid, and is composed of various layers of firmly stamped sand, broken brick and clay, and being over 3 feet thick and partly fused together is impervious to the fluid mass resting upon it. The vault that is sprung over this hearth is very low and instead of being supplied as in fig. 15, with hoppers, has near its middle a large quadrilateral opening that serves for the admission of the huge blocks of native metal, and which is capable of being closed by a plate of fire-clay strengthened with iron. The two doors on the sides of the furnace through which the workmen stir the charge and remove the slag, may be closed in the same manner, all parts of the apparatus exposed to high heat are constructed of refractory fire-brick, and the whole is strongly cramped together with iron bars.

The operation of producing malleable copper in this furnace may be divided into three stages:—

a. Fusing. b. Purifying. c. Refining.

a. FUSING.—The masses of native metal, weighing occasionally as much as 4000 or 5000 pounds, are landed by means of cranes from the ships, and being carried to the furnace, are lowered by the same mechanical contrivance through the quadrilateral aperture in the vault, and deposited carefully upon the hearth. After a charge (which usually amounts to 4 or 5 tons) is put in, all the apertures are closed, and a strong fire made by filling the fire-place with coal, and allowing but little air to pass through the grate. A flame is thus secured which is slightly oxidising at the fire-bridge, but which becomes reducing near the flue. The large blocks become fluid gradually, and, falling to the bottom of the surface, are immediately covered by a slag of fused silicates, which protects the metal from the chemical action of the flames. The complete fusion of the masses requires from twelve to fifteen hours, according to their size; and after it is attained, the heat is still continued for an hour, that the particles of copper mingled with the slag may have time to separate and fall to the bottom. The slag is then taken off by scraping it from the surface of the metal; it is allowed to fall upon the floor, and while still hot is transported to the vicinity of the cupola furnaces, where it is drenched with water, that it may be more easily broken to pieces and prepared for the next smelting.

This slag is a silicate of copper, iron, lime, alumina, &c., and holds from 8 to 10 per cent. of the first-named metal, as a suboxide and in disseminated granules.

b. Purifying.—The copper remaining in the furnaces is now ready for purifying, which is a process resembling that performed in the latter part of the English method, and consists simply in oxidising out certain impurities that may be still mixed with the fluid metal. The fire is made loose, and a large amount of air allowed to enter the furnace. The substances to be removed become oxidised, rise to the surface, and are taken away, and the operation, on account of the comparative purity of the metal, does not last more than about half an hour.

c. REFINING.—The attendant being convinced, by various assays taken from the furnace, that a large quantity of the suboxide of copper has been absorbed by the fluid metal, proceeds now to the refining. A new fire is made, and the air regulated so that the flame becomes as slightly oxidising as possible. A shovelful of charcoal is then thrown upon the metallic surface, and a pole of green wood thrust into the fluid, and allowed to remain as long as a strong development of gas takes place. Assays are now taken to indicate the malleability of the copper, which, when pliable and tough, is protected from further action of the air, by having more charcoal thrown upon it, and is then dipped with ladles from the furnace, and cast into iron moulds. When the metal has slightly cooled, these moulds are reversed, and the ingot falls into a trough of water that is placed below.

The time required for smelting, refining, and casting a charge, is usually twenty-four hours; and with *mass copper* the amount of metal obtained is generally 75 per cent., or more, of the entire quantity put into the furnace. The *barrel work* is reduced in larger charges, and forty-eight hours are often required to complete the process. The *stamp work* is usually smelted in heats of two charges, each consisting of 3 tons, the slag being drawn after the complete fusion of the first, and the second then added. The copper, which amounts to 50 per cent. of the charge, is removed from the furnace at the end of twenty-four hours.

PROCESS II.—REDUCTION OF THE RICH SLAGS IN CUPOLA FURNACES.

The object of this fusion is to extract and secure the copper that is disseminated through the slags which fall at the reverberatory furnace, and thus produce a slag poor enough to be thrown away. The operation is performed in a cupola furnace, remarkable for its simplicity and efficacy. It is cylindric in form, about 10 feet high and 3 feet in diameter, and is composed of a single thickness of fire-brick, supported on the exterior by a firm iron-plate mantle. The whole apparatus is elevated about 3 feet from the surface of the earth upon pillars, and the blast which is introduced through three tuyères, that penetrate the shaft 1 foot from the bottom, is forced in in large quantities with a pressure of 3½ inches of quicksilver. The lower end of the furnace is steeply inclined towards the front side, where an *eye*, or small opening, allows the metal and slag, when fused, to flow out.

A charge of charcoal is then put into the apparatus, and when a proper temperature has been reached, the slag and *anthracite* coal are given in alternating layers. The *eye* is closed until the fused mass at the bottom almost reaches the tuyères, when the clay plug is broken, and the metal and slag are allowed to flow into a basin in the furnace floor. Here the impure copper takes the lowermost level, and the slag floating on the top hardens, is broken, sorted, the portion free from globules of metal thrown into the lake, and the remainder returned to undergo another fusion. The coarse copper, which amounts to nearly 10 per cent. of the charge, contains about 8 per cent. of iron, and is sent back to the reverberatory furnace to be purified. The entire cost of smelting one ton of metal is reckoned at 3*l.* 16*s.* when made from *mass copper*, and at 7*l.* 17*s.* when *stamp work* is employed.

CHAPTER XIII.

REDUCTION OF COPPER BY THE "WET WAY," AND VARIOUS OTHER METHODS.

AGRICOLA, whose work on minerals was published in 1546, tells of a peculiar water which is drawn from a shaft near Schmölnitz in Hungary, that erodes iron and turns it into copper; and in a curious work published in Venice in 1584, two Hungarian rivulets are mentioned, in which by repeatedly placing iron it became "Cyprian" copper. These are the earliest notices I have met with regarding the reduction of copper by the wet way, which is now practised, with many modifications, in various parts of the globe. As a general rule, this method of reduction consists in throwing down the copper from its solution, as a sulphate, in water, by bringing the fluid in contact with pieces of wrought or cast-iron, which latter metal, taking the sulphuric acid from the copper, goes into solution as a sulphate. The copper thus obtained, which is a crystalline powder, more or less pure, as the solution may have been, is dried, fused, and refined, in the usual manner. The application of the "wet way," however, is only found profitable under certain circumstances,—where fuel is dear, where ores have a very low per-centage of metal or a peculiar chemical composition, or where copper occurs in nature as a salt already dissolved in water. In all cases, however, in working on a large scale, the metal must be submitted to one or more fusions before it is brought to a malleable condition.

METHOD OF EXTRACTING COPPER FROM POOR ORES IN USE NEAR LINZ ON THE RHINE.

The Star furnace in which the following processes are carried out, is located about a mile from the left bank of the Rhine near the town of Linz. The ores reduced are brought from several mines in the neighbourhood, from a number in the district of Siegen, and from the region bordering on both sides of the river.

This ore is divided into three classes each of which is subjected to a special process; 1st, *the poor sulphides.* *2nd, the oxides,* and 3rd, the rich sulphides which are reduced entirely by the dry way.

1st. *The poor sulphides,* holding an average of 2 to 2½ per cent. of metal are roasted very cheaply and conveniently in a kind of cupola furnace 10 feet high, circular, and 3 feet in greatest diameter. This furnace when in operation is full of ore and fuel, which are charged in alternate layers at the top, and which sink burning to the lower part where the mass arrives almost freed from its sulphur, and is drawn by the attendant from a suitable aperture left for the purpose. When taken out it has a dark gray colour, but on account of its highly silicious character, is seldom changed by fusion. It is then crushed between iron rollers and brought to the condition of a coarse powder, in order that it may be more easily and completely acted upon by the acid in the next process. From the rollers the ore is thrown into mason-work basins 24 feet square, and 5 feet deep, having a false bottom formed of two horizontal layers of natural basaltic columns placed at right angles to each other, the lower series resting upon stone pillars one foot high. The vats are now ready for the introduction of the gases that are to bring about the solution of the copper; these are produced in the following manner:—Zinc blende is chosen as a cheap material for furnishing sulphur; it is first slightly roasted, that it may be easily crushed, and then brought as a powder upon the hearth of a large retort furnace, and raised to a high heat; a certain quantity of air is forced at the same time into the retorts to furnish oxygen for the conversion of the sulphur into sulphurous acid gas. This goes off through a chimney to the above described vats, being on its way mixed with steam at a low tension, from a kettle heated by the same fire that roasts the blende. The mixed gases enter the space beneath the crushed ore, and, passing through the apertures in the basaltic bottom, penetrate every part of the mass, and coming in contact with the oxides of copper and other metals, formed from the sulphides by the process of roasting, oxygen is absorbed and soluble sulphates are produced and fall in solution to the bottom of the vat. From this the fluid is pumped and thrown into receiving vessels formed of wood built firmly in clay, and while yet hot is brought in contact with bars and scraps of wrought and cast iron, and the copper is thrown down as *cement copper*, while the iron goes into solution in its stead. The finely divided metal is washed thoroughly to free it from iron and other impurities, and then fused in the usual manner and refined in the German hearth, fig. 19.

The remains of the zinc blende left in the retorts are smelted by another company for the metal it contains. The roasted mass has an average of 34 per cent. of pure zinc.

The liquor remaining in the vats after the precipitation of the copper is conducted into broad evaporating pans and brought to a high degree of concentration, and then run into receivers where, upon cooling, a large amount of the sulphate of iron (copperas) is obtained by crystallisation.

The *mother liquor* which remains after the crystals have ceased forming, is made useful in another process, as will be presently shown.

2nd. *The poor oxides* contain, on an average, not over one per cent. of pure copper, which exists principally as a malachite or blue carbonate. The metal is also extracted by the "wet way," but by another plan. Instead of sulphuric acid being used as in the foregoing case, hydrochloric (muriatic) acid which is obtained from a neighbouring soda manufactory at 1*s*. 4*d*. per cwt. is employed as a solvent. The ores are broken to pieces and placed without further preparation, in large wooden vats. Weak hydrochloric acid at the common temperature is then poured in until the mineral is covered, and action is allowed to continue during ten days. The carbonates are easy to dissolve, and they go over into the fluid as chloride of copper. This solution is then drawn off into precipitation vats, the metal precipitated by means of iron, and the cement copper thus obtained melted and refined as in the previously mentioned instance. In this way $\frac{9}{10}$ of the copper in the ore is extracted, the small proportion remaining existing probaby in the form of an insoluble arseniate. This method is remarkably economical on account of the extreme simplicity of the apparatus required, and the fact that the expenditure of fuel is not necessary to insure its success.

Another plan for extracting the copper from poor oxidised ores is in use at the Star furnace. In this case, the *mother liquor*, or the fluid remaining after the iron vitriol has crystallised out, as described in the first mentioned process, is used instead of hydrochloric acid as a solvent. The ore in the condition of a fine powder is placed in vats, each holding about ten tons, and the liquor pumped from the crystallising vessels upon it, and allowed to act fourteen days. This fluid holds in solution beside some free sulphuric acid, the sulphates of iron and alumina, which decompose upon coming in contact with the carbonate of copper, and the soluble sulphate of copper is the result on one side, and the insoluble hydrates of the sesquioxides of iron and alumina on the other. The copper in solution, mixed with much sulphate of iron, is drawn off into another vat and thrown down as *cement copper*, exclusively with wrought iron, since in such a weak and nearly neutral solution of the sulphate of copper, cast-iron would have but a slight action. The cement copper is made marketable by the usual process of fusion and refining.

THE PROCESS OF BECCHI AND HAUPT IN USE NEAR MASSA IN TUSCANY.

This process, which is the invention of the two abovenamed gentlemen, is in operation on a large scale near

Massa, in the southern part of Tuscany. The ores used are extremely poor, having an average of only $1\frac{3}{4}$ to 2 per cent. of copper, which is disseminated as copper pyrites through a large vein of nearly pure quartz. The ore is broken into pieces, not exceeding two inches in diameter and piled in alternating layers with wood, in heaps of 200 to 250 tons. This roasting is finished in ten or fifteen days, and serves chiefly to make the ore friable, that it may be easily crushed beneath revolving stones that prepare it for the second roasting in reverberatory furnaces. The powdered ore being removed to the sole of a reverberatory furnace, is exposed to a high heat, when two to eight per cent. (according to the amount of copper present) of common salt is introduced, and after ten minutes' continued stirring, the charge is drawn out. This introduction of chloride of sodium serves to bring the copper to the form of a chloride, in which condition it can be readily dissolved out. The roasted ore is now thrown into vats which are furnished with layers of straw bundles on the bottom, to serve as filters, and the water which is now poured in, after passing through the mineral mass, runs through apertures in the bottom of the vats into receivers, where it is allowed to settle. It is then passed into a third set of vats, where it is treated with water holding caustic lime in solution. This precipitates oxide of copper, which falls as a powder to the bottom of the vessels. This powder is collected, dried, and fused in a low cupola furnace for a matt, which is subsequently treated for *coarse copper*, and refined in the usual manner.

TREATMENT OF THE SULPHIDES OF COPPER, IRON, &c., AT AGORDO, IN THE DEPARTMENT OF VENICE.

The ore here obtained is a sulphide of iron with minute particles of the sulphides of copper, arsenic, zinc, and lead scattered through it, and remarkable for the small quantity of earthy impurity which it contains. It is exceedingly poor in copper, the average of the 15,000 tons of ore that are produced here per year, being but 1½ per cent. of that metal.

The first process in the metallurgic treatment of the ore is the singular operation known as *kern roasting*. This is accomplished by piling 200 to 220 tons of ore, which is first reduced to pieces two or three inches in diameter, upon a layer of wood, and covering the whole with a stratum of ore that has been once roasted. The pile being kindled, it is allowed to burn slowly, during a period of 8 or 10 months, when it grows cold, and the lumps are found composed of two portions, an outer or oxidised hull, that is broken off with hammers, and a firm kernel in the middle that contains the greater part of the copper as a sulphide. It would appear that the great heat given out by the combustion of the sulphurous exterior brought the interior of the mass to a semi-fluid state, and that the copper in consequence of its natural affinity for sulphur, retained that element, and gradually concentrated itself at the centre, while the easily oxidised iron at the same time lost its sulphur and became an infusible crust. The ore holding 1½ per cent. of copper is reduced by this process to *kernels*, forming 13 per cent. of the original *volume* of the ore, and with an average richness of

4·5 per cent. of copper. These kernels are now mixed with richer ore and fused for matt in narrow cupola furnaces 26 feet high. This, after being roasted, is fused in a peculiar leaning cupola furnace, which produces a *coarse copper* that is nearly free from arsenic and iron, and may be purified and refined at once on the German hearth.

The oxidised portion formed in the first roasting is placed in vats, and subjected to the action of water, which dissolves out as a sulphate 65 per cent. of the copper it contains. The powder is then dried and subjected to a second roasting by being used as a covering for the large heaps while they are undergoing combustion. The powder is again treated with water, and all but $\frac{1}{10}$ of the original amount of copper extracted. The liquor holding sulphate of copper in solution is now heated to about 122° Fahrenheit in contact with cast iron, and cement copper is obtained that is sent to the cupola furnace to be fused for matt in the process above described.

REDUCTION OF POOR SULPHIDES AT VESLEDALEN, IN NORWAY.

The ore here is an iron pyrites containing from $\frac{1}{2}$ to 3 per cent. of the sulphide of copper disseminated through it. It is abundant and easily mined. The ore is roasted in large heaps, and slowly, so that the sulphides are decomposed and changed into soluble sulphates.

The result of this roasting is treated with water, and the soluble sulphate of copper is taken up by the fluid and carried into large vats to be precipitated.

A variation in the usual plan of throwing the copper down from its solution by means of the action of iron, is here observed. That metal being too dear to be employed with profit, its place is supplied by sulphuretted hydrogen gas. This is economically prepared by passing the product of the combustion of pine wood in a retort, over a stratum of red-hot pyrites. The precipitate which contains the copper in the form of a sulphide is however not very pure, and some difficulties are experienced in accomplishing its economical reduction to soluble metal. I may here remark that sulphuretted hydrogen produced in the usual manner with artificially prepared sulphide of iron and sulphuric acid, has been tried as a means of precipitation at the furnace at Freiberg, in Saxony, and not found adapted to the circumstances there.

EXTRACTION OF COPPER FROM THE WATER OF THE WICKLOW MINES.

The water from these mines holds in solution a small quantity of the sulphate of copper, a fact that appears to have been first observed a little over a century ago. This water is led through a series of troughs inclined at an angle of 10° to 12°, and interrupted at intervals by deep chests or *hutches*. Pieces of iron are so placed that the water flows over them, and the metal of the sulphate is thus precipitated as cement copper. This is each morning swept from the troughs into the chests, and at intervals is collected and sold. It yields 50 to 60 per cent. of pure copper, and costs but about 3*l*. per ton for attendance, sifting, &c.

PRECIPITATION OF COPPER AT SCHMÖLLNITZ, IN HUNGARY.

At this locality pure water is led into old workings, and allowed to circulate through the waste heaps of ancient mines, where by the long action of air and moisture, sulphate of copper has been formed. This is taken up by the fluid, which is subsequently collected and conducted into vats and allowed to remain in contact with metallic iron. A cement copper is obtained, having in the most favourable cases 70 per cent. of metal. Experiments here have shown that 200 cwt. of wrought iron, or 300 cwt. of cast iron, are required to throw down 100 cwt. of copper. By this ingenious method 200 tons of cement copper are collected each year.

REDUCTION OF COPPER ORES AT ATVIDABERG, SWEDEN.

The ores consist of a mixture of a small quantity of the sulphides of iron, copper, and zinc, with a large amount of quartz with mica, feldspar, garnet, and other silicates. After having been sorted by hand, they are heaped together with coal and wood in the open air, and roasted. The product is sorted, the larger pieces broken, and all that requires it is subjected to a second roasting. The next operation consists in fusing the roasted ore for the purpose of obtaining a matt. This is accomplished in a cupola furnace, 18 feet high, and 2 feet 8 inches across at the middle, into which three tuyères allow air to be forced by as many copper nozzles $1\frac{1}{2}$ inches in diameter. In making up the charge, it is sought to secure such a mixture, that the slag produced will hold about 45 per cent. of silica, and the matt 25 to 30 per cent. of copper. Such slag appearing best adapted for freeing itself from particles of matt, and at the same time not being of such a nature as to attack the walls of the furnace.

The slag obtained in this fusion that holds less than $\frac{1}{4}$ of one per cent. of copper is cast away; the matt is broken to pieces about the size of the first, and roasted in heaps in the open air six or seven times, until as much as possible of the sulphur and other volatile impurities have been driven off.

Fusion for coarse copper now follows in a rectangular cupola furnace, 18 feet high, and 3 feet across in the shaft. The bottom of the hearth is so deep that the heavy, coarse copper may collect in large quantities and need only be drawn off at long intervals. The lighter slag which collects on the surface with a small quantity of matt resulting from the unreduced sulphates, are drawn off frequently and sorted; the rich sulphides are roasted again and brought again to the fusion for coarse copper, while the slag holding considerable metal is sent back to the first fusion.

The coarse copper, which is unusually free from adulterations, is purified on a small German hearth, (figure 19), and since the principal impurity is iron, and this not being readily fusible, it is found necessary to add, in the operation, a small quantity of silicious slag to combine with the ferruginous oxide as it is formed. When the process of purifying is concluded, the metal *is laded* from the hearth into iron moulds, and is ready for market. The method of smelting in use at the well known mines of Fahlun, in Sweden, where the ores are very similar to those of Atvidaberg, does not differ sufficiently from that given above to require a separate description.

THOMPSON'S PROCESS OF PURIFYING COPPER.

According to this inventor, copper may be purified by melting 100 parts of the metal along with 10 parts of copper scales (black oxide), and 10 parts of ground bottle glass, or other similar flux. After the copper has been kept in fusion for half an hour, it will be found at the bottom of the crucible perfectly pure, while the iron, lead, arsenic, &c., with which it may have been contaminated, will be oxidised by the scales and dissolved in the flux or volatilised. A pure copper has thus been obtained from brass, bell-metal, gun-metal, and several alloys containing from 4 up to 50 per cent. of iron, lead, antimony, bismuth, arsenic, &c. The scales of copper are cheap, being the product of every large manufactory where copper is worked.

CHAPTER XIV.

The Metallurgic Separation of Silver and Copper.

It has been shown, in the foregoing pages, that by taking advantage of the peculiarly strong affinity of copper for sulphur; the slight disposition it possesses, when compared with other metals, to combine with oxygen, and its high specific gravity, that most of the existing metallurgic processes for obtaining the pure metal have been arrived at. There are a number of plans in use for extracting silver from it or its compounds, which rest on these and other important physical and chemical peculiarities. A complete discussion of this subject belongs to the treatise on the metallurgy of silver, and hence, only a brief outline of the various plans will be found here.

THE EXTRACTION OF SILVER BY LIQUATION.

This is one of the most ancient methods of extracting silver from copper. It is founded upon the fact that, when copper containing silver is alloyed with other easily fusible metals, such as lead, and heated to a certain degree above the melting point of the latter metal, but below that of copper, the lead will become fluid and drain or sweat out of the alloy, carrying off most of the silver, and leaving an impure copper behind. In practice, 3 parts of coarse copper holding silver are fused with 10 or 12 parts of lead, or an equivalent portion of litharge rich in silver. The operation is performed in a cupola furnace, and the product run into moulds where it is rapidly cooled, and removed in the shape of disks, 3 to 3½ inches in thickness.

These discs or cakes are carried to a liquation hearth, and being piled on their edges, are heated by means of burning charcoal to the proper temperature. The lead and silver flow from the copper compound, and are collected in a trough which is placed beneath for the purpose. The lead is then treated for the silver it contains, and the copper must undergo a troublesome refining. The plan, as has been before remarked, is being replaced at most furnaces by more complete and direct methods. Copper, however, is still treated according to this system in the Hartz, when it holds between $\frac{1}{5}$ and $\frac{1}{6}$ of one per cent. of silver. It is however assumed by Karsten that as a rule copper that does not contain more than $\frac{1}{4}$ of one per cent. of silver will not pay the expense of liquation. This must depend, however, greatly upon the prices of labour, fuel, lead, &c. In the Mansfeld process, we have already seen that $\frac{1}{12}$ of one per cent. of silver was left behind in the copper, after the liquation was completed; at Altenau, the silver left behind only amounted to $\frac{1}{30}$ of one per cent.

The purification of the copper which remains after the process of liquation is variously accomplished. One of the most usual plans is to treat it in the *Sweating furnace*, where the impure disks are exposed to a current of air, and without becoming melted, still more of the argentiferous lead is sweated out and allowed to run off as an oxide. The lead that existed in the disks at the beginning of this operation to the amount of 20 or 30 per cent., is thus reduced to about 10 per cent., and the copper is now fused in the German hearth to subject it to further purification.

EXTRACTION OF SILVER BY THE AMALGAMATION OF COARSE COPPER.

This process is based upon the circumstance that the silver which exists in coarse copper in a metallic state, when raised to a red heat, in connection with common salt, is changed to a chloride; and when quicksilver is brought into intimate contact with this roasted mass, this chloride is decomposed, and an amalgam with silver and a small quantity of copper and iron is produced. The amalgam thus formed, when removed to cast-iron retorts and heated, is decomposed, the quicksilver distils off, and the silver remaining may be made pure by refining.

This sort of amalgamation is in use at Cziklowa, in Hungary, where coarse copper with ½ of one per cent. of silver is amalgamated to the amount of 100 tons yearly.

The cost of desilvering a ton of coarse copper here, is £5 15*s*. The loss of silver is about 7 per cent. of the amount present.

The coarse copper is produced in the usual manner, roasting in heaps in the open air, and fusion in low cupola furnaces. It is very impure, holding much arsenic and antimony, which prevent the adoption of either Ziervogel's or Augustin's method of extraction. The coarse copper being raised to a bright red heat, is powdered beneath stamps and between revolving millstones. This powder is roasted with salt and then amalgamated in barrels in a manner similar to that usual in the treatment of the ores of silver.

EXTRACTION OF SILVER BY THE AMALGAMATION OF COPPER MATT.

This process which is very similar to that adopted in the usual amalgamation of silver ores, consists in roasting the mixture of sulphides of copper, silver, iron, *et cetera*, that form the matt, as it falls from the furnace, with a proper quantity of common salt and lime.

The first furnishes chlorine, by means of which the various metals are turned into chlorides, while the lime decomposes the chlorides of iron and copper, but leaves the silver to be collected by the quicksilver in the subsequent treatment. At one time this system was in use at Mansfeld, in Prussia, where a matt containing 48 to 53 per cent. of copper and ⅓ of one per cent. of silver was used, but, at present, as has already been shown, it is entirely replaced by the excellent method of Ziervogel. At Freiberg, in Saxony, experiments have been made to prove the practicability of the method, but the process invented by Augustin was found more favourable.

ZIERVOGEL'S METHOD OF EXTRACTING SILVER FROM COPPER BY MEANS OF WARM WATER.

This process is accomplished by changing the sulphide of silver into a sulphate by means of a careful roasting, and subsequently dissolving out the sulphate with warm water. It is sufficiently described in chapter XI. in connection with the Mansfeld method, of which it forms an important part.

AUGUSTIN'S METHOD OF EXTRACTING SILVER FROM COPPER BY MEANS OF A SOLUTION OF SALT.

The circumstance long known to chemists, that the chloride of silver is somewhat soluble in a concentrated solution of common salt, was taken advantage of by Augustin, of Eisleben, in an ingenious plan for separating copper and silver. At Freiberg, in Saxony, this process is in successful operation. A matt is obtained by repeated meltings, holding some 60 or 70 per cent. of copper, and ½ per cent. of silver. This is powdered very finely, and roasted in a furnace constructed upon the same principle as that shown in figure 17. The roasted powder is ground and subjected to a second roasting, and near the end of the process, about 5 per cent. of salt is added, which changes the silver into a chloride. This roasted powder is now brought into vessels similar to those represented by A, fig. 18, and treated with hot brine, which filtering through, carries with it the chloride of silver. Passing into precipitation tubs, it is brought in contact with copper, which throws down the silver in the form of cement silver. This is collected, dried, and refined. The copper dissolved in the precipitation of the silver is carried forward to other vessels and thrown down as cement copper with metallic iron. The lixiviated powder remaining in the vessel A, is carried to a reverberatory furnace and smelted for coarse copper, which is refined in the German hearth. This system, although more expensive than that last-mentioned, is much better adapted for minerals that hold antimony or arsenic.

THE SEPARATION OF SILVER AND COPPER BY DISSOLVING THE COARSE COPPER IN SULPHURIC ACID.

At Rammelsberg, on the Hartz, a coarse copper, rich in arsenic, and holding $\frac{1}{5}$ of one per cent. of silver is separated from the silver, and the same time made valuable as an immediate source for copper vitriol. The copper is granulated and brought as a loose mass into tubs. Hot sulphuric acid is then allowed to trickle over it, and the free access of air provided for. Under these circumstances, the copper slowly oxidises, and immediately becoming a sulphate, is carried off in a solution, which passing through a series of troughs cools, and deposits the salt in rough crystals, the silver at the same time remaining uncombined in the vat. This liquor is then forced back, heated, and made to pass over the copper and silver again. The vitriol is collected, washed, dissolved in the hot mother liquor of previous processes, and run off into vats to crystallise. Fourteen days after the solution has entered the vats, it is considered to have crystallised sufficiently, and the mother liquor is run out and forced into the vitriol pan, again to be used to dissolve the rough salt. The remainder in the dissolving vessels holds about 2 per cent. of silver, and is sent to the furnaces to be smelted. The works are situated near a sulphuric acid manufactory with which they are in connection by a tube, and a yearly production has been reached of 3500 cwt. of vitriol.

SEPARATION OF SILVER AND COPPER BY DISSOLVING THE ROASTED MATT IN SULPHURIC ACID.

At Freiberg, in Saxony, some experiments have recently been tried with good result, in which the silver-holding copper matt, that was formerly roasted with common salt and treated according to Augustin's method, is oxidised in the usual manner by roasting and then brought into tubs, where it is subjected to the action of hot sulphuric acid. The copper is thus dissolved out as a sulphate along with some iron, and the greater part of the silver remains in the tubs undissolved. The cupreous liquor is run into vats where it is allowed to cool and crystallise, and the vitriol formed is sent to market where the copper that it contains sells for some

30*s*. per cwt. more than it would were it in a pure metallic form. The undissolved remainder, containing several per cent. of silver is smelted with lead, and cupelled.

CHAPTER XV.

ON THE ALLOYS OF COPPER.

FROM time immemorial, copper has been used extensively for forming compounds with other metals. The ancients, whose works of art still remain to us, appear to have wrought it chiefly in combination; and, at the present day, the employment of the unmixed metal is less general than that of its alloys. It is not improbable that copper will unite with all the metallic elements, but its alloys with zinc, tin, nickel, and the precious metals are the most valuable and the best known.

BRASS.

This compound, which consists essentially of copper and zinc, is the most generally useful of all the numerous alloys at present known. It is first mentioned by Aristotle, who states that the people who inhabited a country adjoining the Euxine sea, prepared their copper of a beautiful white colour, by mixing and cementing it with an earth found there and not with tin, as was the custom in other lands. The Roman authors of the time of the early emperors, speak of this earth, which they knew as *cadmia,* of converting copper into *aurichalcum,* the ancient name for the zinc alloy. The ancients, however, were not acquainted with the nature of the change that took place, and it is a remarkable example of the slowness by which man arrives at truth when led by experience alone; that brass should have been made during a period of 2000 years, without the metal which brought about the change in the copper being discovered. Agricola was the first to surmise that brass was a composition and not a transmuted metal.

Brass was made with the utmost secrecy in Germany during several centuries, and some families were raised to great opulence by its manufacture. The first brass works erected in England, were put in operation in 1649, at Esher, in Surrey, and the whole of the metal was then made of *"rose"* copper imported from Sweden; but parties interested in the exportation of calamine and importation of foreign brass, succeeded in involving the owner in a disastrous law-suit, which broke up the concern. Manufactories were however soon afterwards erected in Woolwich and Southwark, and in 1663 the first mill for drawing brass wire was erected near Richmond. At present, much brass is founded at Bristol, Birmingham, Holywell, and various other parts of the kingdom.

The properties which cause brass to be more extensively employed than copper are the following:—It is less costly, being partly composed of a metal cheaper than copper, is harder, does not oxidise or rust so easily, and hence is more durable when exposed to atmospheric agencies; it melts at a lower temperature, and is hence better adapted for small castings; it has not that tendency to fill with minute bubbles, which property is so disadvantageous in copper founding; it cuts smoother in the lathe, and will bear a higher polish; its colour may be made to resemble that of gold, which adapts it for purposes of ornament; and lastly, it is more ductile and tenacious, and therefore may be fashioned by the hammer, or drawn into wire more readily than either of its constituent metals.

The general designation, *brass*, embraces compounds of copper and zinc in very different proportions, and the physical properties of the alloy vary largely as one or the other of the metals is in excess. The following table from Mallet, gives the proportions and peculiarities of a number of samples of brass.

Per cent. of Copper.	Per cent. of Zinc.	Colour of Alloy.	Fracture.	Remarks.
88·6	11·4	Reddish yellow	Finely crystalline	
83·0	17·0	Yellowish red	,,	Princes metal
79·6	20·4	Yellowish red	,,	Rolled brass
74·6	25·4	Pale yellow	,,	English brass
66·2	33·8	Yellow	,,	German brass
49·5	50·5	Yellow	Coarsely crystalline	German brass for watchmakers
30·4	69·6	Silver white	Conchoidal	Very brittle

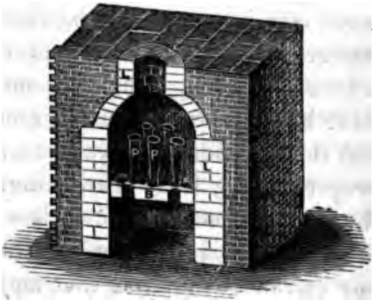
Generally, as the proportion of zinc rises, the hardness and fusibility of the compound increases, and at the same time the malleability and weight decrease. The brass founder in speaking of his mixtures, specifies the amount of zinc only, it being understood that the ratio is to the pound of copper. The accompanying table gives some proportions made use of in practice.

	Bristol Brass.	Muntz Metal.	Muntz Sheathing.	Spelter Solder.	Pale Yellow Metal.	Mosaic Gold.
	ounces.	ounces.	ounces.	ounces.	ounces.	ounces.
Copper ...	16	16	16	16	16	16
Zinc	6	10⅔	9 to 16	12 to 16	12	16½ to 17

Brass is made in two ways:—First, by melting together zinc and copper directly in crucibles. Second, by melting copper with a powdered mixture of coal and roasted calamine, by which means the carbon reduces the zinc to a metallic form, and the two metals coming together are intimately blended.

The first method was patented in 1781, by James Emerson, and is now largely used for manufacturing brass; zinc is melted in a crucible and strips of copper are plunged into it, until an alloy of somewhat difficult fusion is formed; then the heat is raised, and the remaining portion of the copper added. Such are the mutual affinities of the two metals, that the loss which might be expected from the volatile nature of the zinc, is prevented by its being retained by the more stable copper. Brass of the first fusion is broken to pieces, and melted with a fresh quantity of zinc to obtain the finished alloy. Each operation requires about eight or nine hours, and when complete, the brass is moulded into plates and treated for sheets and wire as described in the next section.

FIG. 20.



The second method, which originated in early times, is carried out in furnaces having the construction shown in the accompanying figure. The interior lining L L consists of fire brick, and the furnace bottom B is formed of refractory clay resting on an iron plate, both of which are pierced by holes that serve to furnish draught and allow the ashes and cinders to be drawn off. These furnaces will contain eight or nine fire-clay pots P P, which, in the aggregate, will hold one, to one-and-a-half hundred weight of brass.

The calamine is prepared by breaking the natural mineral into pieces about the size of a walnut. A charge, consisting of about five hundred weight of these lumps, is placed on the hearth of a reverberatory furnace, subjected to fire, and stirred with an iron rake till each piece becomes red hot throughout; this is sufficient to drive off the carbonic acid, and is usually effected in an hour. The loss by this process is 34 to 36 per cent., and the mineral incurs a further loss of 3 or 4 per cent. by picking out worthless fragments after calcination, the fire rendering the ferruginous *deads* more apparent. Care and experience are necessary to perform the operation of roasting, for if it be not complete, the zinc will not unite properly with the copper, and if the ore is over calcined, the brass resulting from it will be brittle, while if the heat is made very intense, a partial vitrification of the silicious matters will take place, and this portion cannot be reduced again by the usual means. When the calamine has been calcined, it is ground to a fine powder, and this is rendered more uniform by passing it through proper sieves; it is then removed to a building called the *buddel house,* where it is washed in an apparatus of peculiar construction, for the purpose of separating any extraneous matters that may still remain in it.

The zinc ore having been thus prepared, it is mixed either with small pit coal or ground charcoal in the proportion of rather more than one bushel of carbon to one bushel of calamine. The most careful manufacturers have almost entirely discarded mineral coal, since they find that the sulphide of iron, with which it is generally contaminated, either spoils the brass or makes it of an inferior quality.

Copper granulated in the usual manner by lading it from the furnace into a vessel filled with water, is then carefully mixed with the calamine and charcoal in the proportion of three pounds of the copper to eight of the powder; with this the crucibles are laden and then placed, as shown in the figure, within the furnace. The pots are now surrounded and covered with fuel, the furnace is closed, and the fire lighted, and left undisturbed for six or seven hours. At the end of this period, the pots are at a white heat. The fire is now revived by the addition of fresh fuel, but as soon as fumes of zinc oxide begin to appear, it is again slackened that the operation may be lengthened, and the two metals have ample time to unite. Three or four hours are required for this purpose, then the orifice in the arch of the furnace is opened, and with a large pair of tongs, the various pots are drawn out, set in hot ashes to retain their temperature, stirred well for a few minutes, and then all the melted metal is deposited in one. The scoria is now carefully skimmed off, and the fluid remainder poured into moulds formed of two blocks of granite laid half an inch apart upon iron bars. By this means plates are formed that are usually 5½ feet long, 15 to 16 inches wide, and half an inch thick, weighing about 108 pounds. The entire operation requires from eight to twenty hours, depending on the nature of the material and the size of the furnaces. In the older manufactories the time employed was much greater, sometimes reaching as much as four or five days. The moulds of granite, which were once imported at considerable expense from the Continent, are now obtained from Cornwall, where an excellent material for their construction is found.

The cast plates are now transported to the rolling-mill, where they are brought to the form of sheets, which, by means of a pair of large shears, are cut into narrow strips. These are passed a number of times through rollers till they arrive at the condition of ribands, which are then cut into long *strings*, and passed to the wire-drawing department. The process of drawing wire from brass does not differ essentially from that pursued in making the same commodity from iron:—A thin plate of hardened steel is pierced with numerous holes, gradually decreasing in size until as small as the diameter proposed for the finest wire. These holes must be made with the utmost care, perfectly round, and highly polished. The plate is then smeared with grease, to decrease friction; the coarse wire is first drawn through the largest hole, then through the next smaller, and so on in succession until the smallest desirable size is reached. The finest wire is often passed, in the last stages of its manufacture, through holes drilled in rubies. During the process of rolling and drawing, it is necessary to anneal the metal frequently, which is accomplished by raising it to a little below a red heat, and then suffering it to cool gradually, by which treatment it becomes soft and pliant. It is not plunged into water, as is done with copper wire, though by so doing it would not be hardened like iron and steel wire when thus treated. The largest consumption of brass wire is in the manufacture of pins, and here it performs an office that would be but poorly filled by copper. Brass foil is made from a very thin sheet brass, formed of 11 parts of copper to 2 of zinc. It is beaten out under a hammer worked by water-power, which gives 300 to 400 strokes per minute, from 40 to 80 leaves being laid on each other. When brass is wanted for working into small castings, or for making other alloys, it is run into small ingots, about 8 inches long and 2 inches broad, in which form it is sold.

BRONZE.

Bronze, like brass, is the generic name for a large class of alloys. Instead of zinc, however, tin is here the secondary metal. The term is, moreover, made to embrace compounds, not only of copper and tin, but also those containing lead and zinc in small quantities, as third or fourth constituents. This alloy was one of the earliest known, and in many connections it took the place of the dearer iron. Among the ancients it was largely used for casting statues, and many articles of domestic economy, and weapons, which have been left us by the Grecians, Romans, Celts, and Peruvians, are composed of it. In the middle ages it grew to be important as a material for bells, and in more modern times it has been largely used for cannon; and although it does not equal brass in the amount made and used, yet the objects to which it can be applied are no less numerous and important. Like brass, it is harder and more fusible than copper, and denser than the mean of its constituents. Its colour is usually reddish-yellow; but when exposed to the air, a basic carbonate of copper is formed which possesses the greenish hue commonly seen on the surface of statues, and by which the alloy is best known. This crust is much admired, and is hence often produced on new statues by moistening their surface with salts or acids. A solution of 4¼ parts of sal ammoniac, 1 part of oxalic acid, in 94½ parts of distilled vinegar, answers this purpose very well.

Bronze possesses the singular property of becoming so malleable, that it may be hammered and coined when it is heated and rapidly cooled, as by plunging it into cold water; and by heating it and allowing it to cool slowly, it may be made to regain its former hardness and brittleness.

The following table will show the nature of various alloys of copper and tin, and the uses to which they may be applied.

Copper.	Tin.	Colour.	Use.
84·3	15·7	Reddish yellow	Cannon metal
81·1	18·9	Yellowish red	Cannon metal and works of art
80·0	20·0	,,	Metal for axle boxes
78·0	22·0	,,	Large bells
34·9	65·1	Whitish	Small bells
15·2	84·8	White	

The bronze of the ancients varied widely in its nature, as will be seen by the following analyses:—

	Copper.	Tin.	Lead.	Iron.	Zinc.	Analysed by
Bronze of Celtic weapons	92·0	6·7	0·69	0·29	...	Fresenius
An Egyptian dagger	85·0	14·0	...	1·00	...	Vauquelin
Coin of Alexander the Great	87·9	11·6	...	...	...	Schmeid
Ancient Athenian coin	88·5	10·0	1·5	...	...	Mitscherlich
Coin from the time of Pompey	14·2	8·5	16·1	0·2	...	Phillips
Coin from the time of Hadrian	85·7	1·1	1·7	0·7	10·8	Phillips

It is remarkable that in the coins originating in Greece, or in any of the Grecian colonies, zinc has not been detected, while among the Roman coins that metal often occurs as a constituent.

According to the experiments of Hoffman, it appears that for statuary bronze the extreme proportions that can be used with advantage are—1st, the reddest and richest in copper, and hence the most expensive alloy may consist of 84·42 per cent. of copper, 11·28 zinc, and 4·3 tin; 2nd, the poorest in copper and cheapest gold yellow alloy, may be formed of 65·95 copper, 31·56 zinc, and 2·49 tin. The bronze statue of Louis the Fourteenth, cast in 1699, has 91·40 per cent. copper, 5·53 zinc, 1·70 tin, and 1·37 lead. The Lessing statue in Brunswick is composed of 89·16 copper, 0·49 zinc, 10·24 tin, and 0·10 lead. In the arts bronze is often used to form substances intended to withstand pressure and friction; an excellent alloy for this purpose consists of 80 copper, 18 tin, 2 zinc. Stephenson recommended the following composition for locomotive axle boxes—79 copper, 8 tin, 5 zinc, 8 lead; and a compound used at Seraing in Belgium for the same purpose consists of 86 copper and 14 tin.

CANNON METAL. The proportions of the metals selected for this species of bronze are such as produce the toughest and most indestructible alloy. It is among the richest in copper of all the bronzes, and consists generally of from 88 to 90 per cent. of that metal, with 10 to 12 per cent. of tin, the former metal furnishing the tenacity, the latter hardness. The greatest care is necessary to keep the compound clear of sulphur, lead, iron, and arsenic, for any of these would lessen the value of the metal for the required purpose, lead producing a fusible mixture, and arsenic and sulphur causing brittleness.

The accompanying cut will give an idea of the plan adopted for casting cannon at Toulouse in France. The melting furnace, A, is of the reverberatory class; a good fire built on the grate, G, melts the charge that is placed on the hearth at A. Close to the furnace is a pit, M, in which the moulds, C C C, are built of the required shape, in an upright position, from a mixture of clay, horse-manure, and cow-hair. Between the mouth of the furnace and the moulds, canals are made for the passage of the fluid metal. The furnace is charged with old bronze and copper bars, and after these are brought to a fluid state, the necessary tin is added in the form of small ingots; the slag which forms on the surface is drawn off, the metal well stirred with poles of dry wood, that the mass may become homogeneous. At the end of eight or nine hours, the *charge* has become quite fluid, and by opening the aperture at I, the metal is permitted to flow into the forms. After forty-eight hours' gradual cooling, the guns are ready to be removed from the pit; they are then bored, turned, carefully examined for flaws, and subjected to the various tests thought necessary to prove their security from bursting when brought into service. The metal best adapted for large guns has been shown by experience to consist of 11 parts of tin to 100 of copper, while that proper for small field-pieces should consist of a mixture of 8 to 9 parts of tin to 100 of copper.

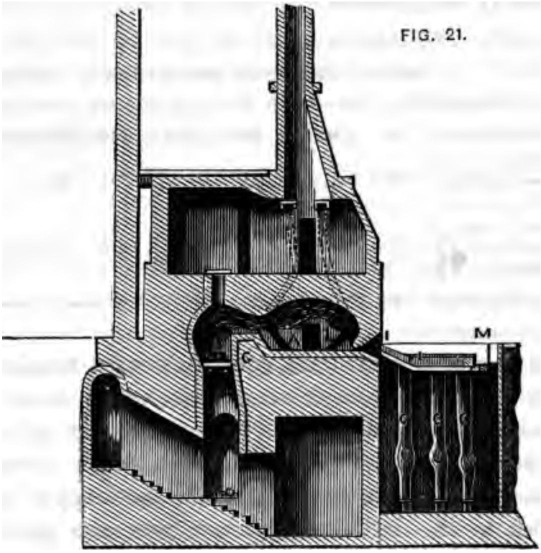


FIG. 21.

Bell Metal.—This is a bronze containing a greater per centage of tin than gun metal; the standard proportions are 78 parts of copper and 22 of tin; but zinc, antimony, lead, nickel, and iron often occur in the prepared casting, and are either introduced with the view of producing particular tones, or are impurities consequent upon the employment of old brass or bronze in their manufacture. The accompanying analyses show the composition of some ancient and modern bronzes of this species.

	Copper.	Tin.	Zinc.	Nickel.	Iron.	Analysed by
English bell metal	80·	10·1	5·6	0·0	0·0	Thompson
Darmstadt chimes, cast in 1670............	73·9	21·6	0·0	1·2	2·1	Heyl
Bells of Rouen, cast in the 12th century.........	71·0	26·0	1·8	0·6	1·6	Girardin

The use of a compound consisting of a number of metals is, however, not to be recommended, since, as a rule, the pure hard alloy of tin and copper gives the clearest sound, and the introduction of silver does not produce that beneficial effect which the fancy of poets ascribes to it. Bells of various tones are produced chiefly by varying the manner of casting, and the size and proportions of the instrument. The apparatus used in their manufacture does not essentially differ from that employed for casting cannon, though provision need not be made for such a high heat, since the usual per centage of zinc makes bell metal comparatively fusible.

The composition of *gongs* or *tom-toms*, which are instruments formed like disks or shallow pans, and being beaten upon by a stick covered with leather, sometimes take the place of bells, consists of about 77 of copper and 22 of tin. The above-mentioned property of bronze, which enables it to be made malleable by rapid cooling is taken advantage of in the construction of these instruments; the fused alloy is first cast into a mould, after hardening, it is withdrawn, and placed in a furnace where it is raised to a cherry heat, then it is laid between two iron disks, plunged into water, and allowed to cool; it is now hammered to the desired form, and subsequently tempered by heating and slow cooling.

SPECULUM METAL.

This alloy contains still more tin than bell metal: the standard proportions are 66·6 per cent. of copper and 33·4 per cent. of tin; but these proportions are only approximately adhered to. A small addition of arsenic is often made, but too much will cause the alloy to be easily attacked by the air: 32 parts of copper, 16 of zinc, and 2 of arsenic have been used, and Kampmann found by the analyses of an excellent Chinese mirror, that it consisted of 80·8 copper, 9·5 lead, and 8·5 antimony. The speculum of the great telescope of Lord Rosse is composed of copper with a little less than one-half its weight of tin. Such an alloy is hard and brittle and is capable of receiving a remarkably fine polish.

Bronze for Medals or Medallions. This alloy consists usually of copper, with from 5 to 10 per cent. of tin, though a little lead and zinc do not injure the metal for the purpose. The compound is melted, well mixed, poured into moulds, and when hardened quickly plunged into water. It may now be brought under a press, where it will receive a good impression, and subsequently by slow cooling it may be hardened. The medal thus formed may be given at once a delicate bronze colour by brushing it over with a solution consisting two parts of sal ammoniac, one part of common salt, one of saltpetre, one of ammonia, and 96 parts of strong vinegar. This when carefully applied, gives the beautiful shade that is so much admired, and which, by the application of the same mixture may also be imparted to copies of works of art or other subjects taken in pure copper.

GERMAN SILVER OR ARGENTAN.

In China this compound has been long known and extensively used, and for many years it has been imported from that empire into Europe under the name of *packfong*. In 1776 it was recognised as an alloy of copper, zinc, and nickel, and since it was subsequently largely manufactured at Suhl, in Henneberg, in Germany, and from thence sent to England, it has received the name of German silver.

At present, very large quantities are manufactured in England, and particularly at Sheffield, where it is formed into forks, spoons, vessels for the table, and various other articles of domestic use, and being plated with silver by the electrotype process, is sold as a substitute for silver to all parts of the globe. When well made, it cannot be distinguished by an unpractised eye from many of the the silver alloys even when brought on the touchstone, but by dissolving a small piece in nitric acid, and adding a few drops of hydrochloric acid, no milky precipitate is formed, which would be the case, were a silver alloy treated in the same way. Good German silver is tougher and harder than brass, and resists the action of the air much better; it is susceptible of a very high polish, and when properly prepared, may be rolled into plates, drawn as wire and wrought with the hammer.

The following analyses will serve to show the elemental composition of several varieties.

	Copper.	Nickel.	Zinc.
Chinese packfong	43·8	15·6	40·6
English German silver	61·3	19·1	19·1
Berlin Argentan	52·0	26·0	22·0
Sheffield German silver	57·0	24·0	13·0

The mixing of the materials which constitute this alloy, takes place in crucibles similar to those used in the manufacture of brass. The zinc is first melted with half the necessary copper, and the compound is cast into thin plates that may be readily broken. In another pot the nickel is melted with the remainder of the copper, and after having been well stirred, the alloy of copper and zinc is added piece by piece, until the proper proportions are arrived at, when the contents of the pot may be cast into ingots ready for use. The purity of the original metals is of the first importance in securing a good German silver, a small amount of arsenic will render it brittle and easily tarnished, and since nickel, on account of its chemical affinities is seldom free from that element, it is a matter of considerable difficulty to obtain a perfectly pure alloy. The discovery of a natural sulphide of nickel in Sweden, which is free from arsenic, has been very advantageous to the manufacturers of German silver, by enabling them to supply in larger quantities a compound closely resembling one of the noble metals.

ALLOYS OF COPPER WITH SILVER AND GOLD.

These two metals which are so largely used for making coins and jewellery, would be too soft and easily destroyed by friction were they employed in an entirely pure condition. They are, therefore, generally alloyed with some cheaper metal to give them the requisite durability. Copper will unite with either in any desired proportion, and without destroying their malleability. The small coins of Germany are often very rich in copper, so that after being a short time in use, they become quite red. The silver groschen, made according to the Prussian law of 1821, have but 2 parts of silver to 7 of copper. Modern French silver coins have 9 parts of silver to 1 of copper; and those of England are somewhat richer, having 37 parts of silver to 3 of copper.

The foregoing are the principal alloys of copper, there are a number of others, the names and properties of which are known to artisans; among them are *tombac,* consisting of 84·5 copper and 15·5 zinc; *Manheim gold,* 70 copper and 30 zinc; pinchbeck, 88 copper and 11 zinc; *cymbal metal,* 80 copper and 20 tin; *Bath metal,* 32 parts of copper and 9 zinc; *gilding bronze,* 82·3 copper, 17·5 zinc, 0·24 tin, and 0·02 lead; *white metal for buttons,* 32 parts brass, 4 parts zinc, and 2 of tin; *tutenag,* 45·7 copper, 36·9 zinc, 17·4 nickel; *Chinese white copper*, 40·4 copper, 31·6 nickel, 25·4 zinc, and 2·6 iron.

An alloy of copper and arsenic, when consisting of 90 copper and 10 metallic arsenic, is white, slightly ductile, and more fusible than copper, and is not attacked by the atmosphere. It is used for the scales of the thermometers and barometers, for dials, candlesticks, &c. It is formed by smelting arsenic and copper clippings together in an earthen crucible, under cover of a layer of salt.

With iron, copper will combine in small proportions, one per cent., however, causes the iron to weld badly, and a small quantity of the first-named metal combined with copper, injures its value for manufacturing purposes. With aluminum, it forms an alloy of considerable malleability and great hardness, and which is capable of taking a very high polish.

CHAPTER XVI.

THE WORKING OF COPPER AND THE MANUFACTURE OF CUPREOUS PRODUCTS.

THE PROCESS OF MAKING ROSETTE COPPER MALLEABLE.

THE English system of smelting copper results in a product freed by the final "poling" of that portion of the suboxide which renders the metal brittle or "cold short" under the hammer. This however is not the case with copper purified on the German hearth and generally brought to market as *rosette* copper. The last operation here, as has been shown (Chap. XI.)

leaves from 1 to 20 per cent. of the sub-oxide of copper dissolved in the metal. This substance must be removed before the copper can be wrought, and the refining is often performed by the manufacturer or artisan who purchases the metal, upon a small hearth arranged like that shown in fig. 19. Instead however of the nozzle being inclined at a large angle so as to throw the air directly upon the molten metal, it is here so nearly horizontal that the charcoal, which lies upon the surface of the fluid, is only impinged upon. The object of the operation, like that of "poling" is to bring about a reduction of the sub-oxide and produce a copper without adulteration. The rosettes are piled in layers with good charcoal and fused, often with the use of highly heated air; the charcoal and oxygen furnish carbonic oxide which acts as a reducing agent upon the sub-oxide, and changes it into metallic copper. Assays are taken frequently and tried while cold and hot beneath the hammer; when the metal bends without cracking on the edges, the process is deemed complete, the charcoal is removed, the contents of the hearth allowed to cool slightly and then laded out of the hearth into iron moulds prepared for the purpose. This process which is usual in Germany, is known as the *Hammergaarmachung*.

ROLLING AND HAMMERING.

The copper brick or ingot formed in the refining process is often taken directly from the mould, and while yet hot carried to a rolling apparatus similar in its general arrangement to that commonly employed *in working* iron. Eight or ten passages between the iron cylinders are sufficient to bring it to a long plate an inch or less in thickness. The heat gradually decreases until the plate becomes dark, it is then removed to a reverberatory furnace and placed upon a series of iron bars which keep it suspended between the hearth and the vault. Flames striking over the fire-bridge pass along the surface of the plate and are carried off through flues leading downward. Thus the heat is raised gradually to a bright red, when the plate is again brought between the rollers. This is continued until a certain thinness is reached, when two or more plates are laid one upon the other and heated and rolled together.

At the copper rolling mill at Rothenburg in Prussia, which is understood to be the most extensive on the continent, the largest plate that has been rolled was 12 feet long, 9 feet broad, and half an inch thick. The copper plates thus prepared may be plunged into water to remove the dark scales, and sent to market, or may be further wrought into kettles, &c. Kettle bottoms or entire kettles are hammered from the flat plate. For this purpose tilt hammers moved by steam or water power are employed, the striking end of these tools is sometimes two or three feet long that it may reach the interior surface of a deep vessel. One kettle is rarely beaten out at a time; ten or twelve plates are usually fastened firmly to each other at the edges, and the entire mass hammered into shape together. The edges are then separated, the vessels taken apart and given into the hands of workmen who beat the sides and bottoms smooth with small hammers. In the fabrication of very large copper bottoms for the boilers in sugar refineries a singular plan is adopted; the huge plate of metal is cut into a circular form and laid upon a heavy horizontal cast iron ring that serves as an anvil; by means of a rope running through a pulley fixed in a beam above the plate, a ball of iron two or three hundred pounds in weight is raised by men or steam power 4 to 6 feet, and allowed to fall successively upon the central parts of the malleable disk which gradually assumes the form of a basin. A plate 8 feet in diameter may thus be beaten 2½ feet deep in a day.

The process of drawing copper into wire is similar to that described in Chapter XV., as usual with brass.

SOLDERING COPPER.

Copper is soldered by making the surfaces to be joined quite bright, free from oxide, and level, and covering them with sal-ammoniac or rosin or both, before applying the hot soldering iron to fuse them together with the alloy. The strong solder or alloy of the coppersmith consists of 8 parts of brass and 1 of zinc, a still stronger solder may be made of 3 parts of copper, and 1 of zinc, and a softer consists of 6 parts of brass, 1 of tin, and 1 of zinc.

SULPHATE OF COPPER OR COPPER VITRIOL.

Among the commercial products formed from copper, its compound with sulphuric acid, known as blue vitriol, holds an important place. It is the substance from which most of the chemical preparations of the metal are obtained; it supplies in the art of dyeing a means of securing certain varieties of black, brown, green, and blue; it is sometimes administered as a medicine; as a protection against dry rot its solution has been occasionally employed to saturate timber, and large quantities are used in the art of electro-metallurgy.

The separation of copper from other metals, by the wet way, furnishes one of the most important sources of the salt; but when it is made the object of special manufacture from the metal upon a large scale the following plan is adopted:—A reverberatory furnace of usual construction is charged with old copper plates, and brought to a white heat. Sulphur is now thrown in and the draught closed until a sub-sulphide has been produced, the draught is then opened and air coming in contact with the hot sulphide, a sulphate is formed, together with an insoluble oxide. The roasted mass is then treated with hot water until all the sulphate has been carried away, and the insoluble remainder is again heated with sulphur in the furnace, and lixiviated, and this process repeated until the whole of the copper is changed to a sulphate. The solution is run into vats and allowed to deposit crystals which are drained and sent to market.

Another plan for obtaining this commodity is largely in use. The scales which fall in hammering and rolling copper, are carefully collected and mixed with strong sulphuric acid in wooden vessels lined with lead. The mixture is warmed and agitated by steam being blown into it through a tube opening near the bottom of the tank. When the acid has become saturated with oxide of copper, it is drawn off into other leaden vessels and allowed to crystallise.

Blue vitriol often comes into the trade largely adulterated with iron vitriol of copperas. This impurity, however, may be detected by the greenish colour, when much iron is present.

BLUE VERDITER.

When a solution of the nitrate of copper has its copper precipitated as an oxide by adding lime in a pure state, and the cupreous product is triturated with lime after it is nearly dry, the result is a substance of a fine velvety lustre, known as *blue verditer*. The *cendres bleues en pâte*, of the French, is a composition resembling this in many respects. It is made by treating a solution of the chloride of copper with hydrate of lime. The precipitate thus obtained is mixed with a solution of pearlash and ground in a colour mill. It is sold as a paste for painting, or printing paper hangings, or when dried and worked into the proper form it is used by artists for crayons.

SCHWEINFURTH GREEN.

This beautiful colour was discovered in 1814, in Schweinfurth, and the method of its preparation kept a secret until 1822, when the researches of Liebig indicated its nature, and opened its manufacture to the world. Its preparation is easy;—50 lbs. of sulphate of copper, and 10 lbs. of lime are dissolved in 20 gallons of good vinegar, and a boiling hot solution of white arsenic quickly added. The mixture is stirred several times and then allowed to subside. The pigment is cooled on a filter, dried, powdered, sifted, and after rubbing with a little muriatic acid is ready for use.

THE ACETATE OF COPPER OR VERDIGRIS.

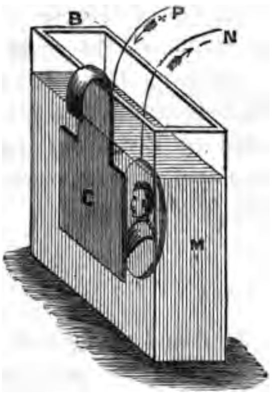
This salt is employed in painting and in calico printing. When pure, it has a fine bluish-green colour, is soluble in ammonia, and contains 43 per cent. of the oxide of copper. The best verdigris is manufactured in France, at Grenoble and Montpellier, by packing thin sheets of copper in casks with alternate layers of fermenting skins and pulp of grapes, which form the refuse of the wine presses after nearly all the juice has been extracted. From 15 to 20 days are required to corrode the plates sufficiently. They are then taken from the casks, leaned against each other, and frequently moistened with water during several weeks. The verdigris, which then is found in a scale covering the surface, is scraped off and the copper plates subjected to a fresh treatment, until they are entirely converted into verdigris. The salt is now kneaded into a paste, packed in leathern bags, dried, and sold. The verdigris made in northern Europe and in England, is usually manufactured by employing cloths steeped in pyroligneous acid, instead of the refuse of the wine-press, and is not equal to that made by the former method. Chalk is sometimes used to adulterate verdigris, but may readily be detected by dissolving the suspected substance in hydrochloric acid, in which case in the presence of the lime, bubbles will appear.

ELECTRO-METALLURGY.

In the early stages of the beautiful and valuable art of depositing metals from their solution by galvanic agency, the metal which is the subject of this treatise was the only substance sought to be precipitated. In the year 1837, while observing the action of a constant battery formed with a solution of the sulphate of copper, Mr. Spencer noticed that the plate used for the negative pole became coated with metallic copper with the exception of those spots upon which wax had been accidentally dropped. This circumstance called attention to the subject, and subsequent experimenters, of whom Walker, Elkington, Smee, and Murry have been eminently successful, gradually developed the art to its present condition.

When copper is deposited, the sulphate of that metal is the salt, the solution of which is uniformly employed. The required solution is formed from the blue vitriol of commerce by dissolving that substance in cold water, until no more will be taken up, then allowing it to stand until it is quite clear, and adding one-fourth more water, since a saturated solution is not desired. This fluid is then poured into a vessel, B, fig. 22, made of earthenware or glass, and a copper plate, C, is hung over the edge, so as to be almost entirely immersed. The object to be copied or plated—as the medal M—is attached to a wire, and hung also in the solution opposite and parallel with the plate. An electric current, which may be generated by any species of battery, but best either by Daniel's or Smee's, is passed through the wire P to the copper plate. The vitriol, in solution, is thus decomposed, the electro-positive element or the copper, going to the negative pole or the medal M, and forming *a uniform* and solid coating upon it, while the sul-

FIG. 22.



phuric acid thus set free, attacks the copper plate C, and renews in the solution the sulphate which is decomposed by the current.

This action may be continued until a thick coating forms on the surface of the medal, the deposition of which will be slow or rapid according to the strength of the current of electricity. Any other object having a conducting surface, placed at M, will likewise be coated with the metal in solution, and thus a cheap material may be so plated that it will resemble the more valuable metal thrown down upon it.

If, however, the surface of M is not a conductor, no metal is deposited, hence, in the foregoing instance, in order to prevent the medal from being encased in a scale of copper, which could not be readily removed, its back part and edge are covered with wax, and only its face left exposed, and this surface, that the cast may not adhere to it, is moistened with a little sweet oil and rubbed with silk till it appears dry.

To coat objects which are non-conductors, a fine powder of graphite or blacklead may be laid thinly over the surface and introduced into the irregularities with a brush; the object may now be treated as in the case of the medal, and thus, by etching, so as to form a rough exterior, glass or porcelain may be given a permanent coating of pure copper. The above-described process, it is evident, will only give a reversed impression of the medal. In many cases it is desirable to have an exact copy of the object; here, an exact impression of the surface to be copied, is taken in fusible metal, wax, a composition of glue, plaster of Paris, or gutta percha, and the metal thrown down upon this as a mould.

Not only is it possible by the processes of electro-metallurgy to form facsimiles of various objects in copper, but the same may be formed in various alloys, by throwing down together, from a mixed solution, the metals of which the alloy may be composed.

When brass is to be deposited by this method, a solution is placed in the vessel B, having the following composition—

1 part of sulphate of copper in 4 parts of hot water.
8 parts of sulphate of zinc in 16 parts of hot water.
18 parts of cyanide of potassium in 36 parts of hot water.

These are mixed, 250 parts of water added, and the objects to be copied introduced as above-described. Instead of a copper plate at C, one of brass is used, the solution is kept during the operation at a heat approaching boiling, and a powerful battery is employed.

The applications of the principle of electro-decomposition in the arts are very numerous. In the working of copper, the most important are those which are connected with printing and engraving. A hard copper plating is thrown down on the face of common type, thus greatly increasing their durability, and entire stereotype plates are made by taking the cast of the type in gutta percha or plaster of Paris, and depositing a thick plate of copper upon this reverse mould. Solid copper plates for the purpose of the engraver, which on account of the difficulty of casting copper without bubbles, are often imperfect when made by the dry way, are formed with certainty by depositing the metal from its solution. A more beautiful employment of the art is found in reproducing elaborately engraved plates. Usually, copper plates after passing through the press 600 to 1000 times, become so worn as to give indistinct impressions; by electro-metallurgy, however, these plates may be multiplied indefinitely, and the sharpness of the originals retained. Through the kindness of Col. James, I had recently the pleasure of inspecting the admirable electrotype department of the Ordnance Survey at Southampton. The plates, engraved by the usual processes, are duplicated by a strong battery, essentially by the plan above described. Thus, perfect fac-similes of the most elaborate works are obtained in a few weeks and at a comparatively small cost, and the clear engravings of the survey maps are by this means produced at a much lower cost than could otherwise be done.

To the lover of natural history the electrotype offers two processes of exceeding beauty and value. By a simple adaptation of the principles above detailed, the most accurate copies may be made of any vegetable or animal substance that will remain undecomposed in solution for a few hours. Thus the most delicate hairs and tendrils of plants, and the smallest insects may be coated with metal, and preserved. The second process, which is known as "Nature-Printing," is generally used for obtaining impressions of plants, and is often so successful that unpractised eyes mistake a simple picture made by this method for an excellently dried specimen. It has been used in the preparation of that elegant work "The Ferns of Great Britain and Ireland." The plant to be copied is pressed with great force upon a plate of lead, and thus made to leave a delicate and perfect impression of itself upon the soft metal. Then by means of electrical action, these plates of lead have copper deposited upon them until a stratum is formed heavy enough to print from.

This is then supplied with the various appropriate colours, and impressions are taken as in ordinary copper plate printing, the inked plate, with the sheet of paper laid on it, being passed through a pair of rollers, one of which is covered with four or five thicknesses of blanket, which, pressing the damp paper into all the indentations upon the plate, causes the peculiar raised or embossed appearance of the impression.

The scientific world is deeply indebted to the eminent savan, Professor Haidinger, of Vienna, who, in 1850, made the suggestion which led to this application of electro-metallurgy.

CHAPTER XVII.

THE STATISTICS OF COPPER.

THE following table[*] gives, as nearly as can be ascertained, the amount and relative proportion of copper produced by the various countries of the globe. It will be observed that within 25 years the number of tons sent to market more than doubled, an increase which is chiefly due to the discovery of new cupriferous regions in Chili, Cuba, Australia, and the United States. Yet during the same period the price of the metal has risen very notably.

[*] Whitney's "Metallic Wealth of the United States."

	1830.		1840.		1850.		1853.	
	Tons.	Per cent.	Tons.	Per cent.	Tons.	Per cent.	Tons.	Per cent.
Russian Empire	3·800	14.9	4·600	11·2	6·450	11·8	6·500	11·7
Scandinavia	1·500	5·9	1·500	3·7	2·000	3·7	2·000	3·6
Great Britain	13·200	51·7	13·000	31·7	14·700	26·8	14·500	26·0
German States	1·100	4·3	1·250	3·1	1·400	2·6	1·450	2·6
Austrian Empire	2·150	8·4	2·650	6·5	3·300	6·0	3·300	5·9
Rest of Europe	·500	2·0	·700	1·7	1·000	1·8	1·000	1·8
Turkey	·500	2·0	1·000	2·4	1·000	1·8	·600	1·1
Africa	...	...	·100	·2	·600	1·1	·600	1·1
Asia	2·500	9·8	2·500	6·1	3·000	5·4	3·000	5·4
Australia and New Zealand	...	...	...	...	3·500	6·4	2·950	5·3
Chili	·200	·8	9·000	22·0	12·500	22·9	14·000	25·1
Rest of South America	...	...	·100	·2	1·200	2·2	1·300	2·3
Cuba	...	...	4·500	11·0	3·400	6·3	2·500	4·5
United States and Canada	·50	·2	·100	·2	·650	1·2	2·000	3·6
	25·500	...	41·000	...	54·700	...	55·700	...

The production of the globe is at present about

68,500 tons, Great Britain standing first upon the list followed closely by Chili and the United States.

The records of the Cornish "ticketings" form an interesting series in which to trace the history of the progress of the copper trade by England. They extend back more than a century with considerable completeness, and indicate in a striking manner the pre-eminence and importance of the Cornish mines as a source of national wealth. The gradual decline in the percentage of the ores sent to market, has been justly ascribed by Sir Charles Lemon, to the improvements which have taken place in metallurgic processes which have made the profitable employment of poorer ores possible. Further, the importance of rich foreign ores and regulus, has necessitated (see Chapter X.) the use of minerals holding a lower percentage of metal, in order to produce the proper working mixture.

TABLE II.

Showing the amount and value of copper ores sold in Cornwall from 1726 to 1775, inclusive.

	Ten years' tonnage.	Average price per ton.	Amount.	Average annual tonnage.	Average annual amount.
		£ *s.* *d.*			
1726 to 1735 ...	64,800	7 15 10	473,500	6,480	47,350
1786 to 1745 ...	75,520	7 8 6	560,106	7,552	56,010
1746 to 1755 ...	98,790	7 8 0	731,457	9,879	73,045
1756 to 1765 ...	169,699	7 6 6	1,243,045	16,970	124,304
1766 to 1775 ...	264,273	6 14 6	1,778,337	26,427	177,833

TABLE III.

Showing the quantity of copper ore, in tons of 21 cwt., sold at the Cornish "ticketings" with its money value, the amount of fine copper it contained, and the standard and percentage from 1771 to 1859.

	Tons of Ore sold.	Fine Copper in Ore.	Money value.	Standard.		Per cent. yield.
			£	£	s.	
1771	27,856	3347	189,609	81	0	12
1772	27,965	3356	189,505	81	0	
1773	27,663	3320	148,431	70	0	
1774	30,254	3630	162,000	68	0	
1775	29,966	3596	192,000	78	0	
1776	29,433	3532	191,590	79	0	12
1777	28,216	3386	177,000	77	0	
1778	24,706	2965	140,536	72	0	
1779	31,115	3734	180,906	73	0	
1780	24,433	2932	171,231	83	0	
1781	28,749	3450	178,789	77	0	
1782	28,122	3375	152,434	70	0	
1783	35,799	4296	219,937	76	0	
1784	36,601	4392	209,132	72	0	
1785	36,959	4434	205,451	71	0	
1786	39,895	4789	237,237	75	0	
1787	38,047	...	190,738	...		
1788	31,541	...	150,303	...		
1789	33,281	...	184,382	...		
1790	...	...	...	...		
1791	...	...	...	...		
1792	...	...	...	...		
1793	...	...	...	...		
1794	42,816	...	320,875	...		
1795	43,589	...	336,189	...		
1796	43,313	4950	356,564	...		
1797	47,909	5210	377,838	...		

	Tons of Ore sold.	Fine Copper in Ore.	Money value.	Standard.		Per cent. yield.
			£	£	s.	
1798	51,358	5600	422,633	...		
1799	51,273	4923	469,664	121	0	
1800	55,981	5187	550,925	138	3	
1801	56,611	5267	476,313	117	5	8·8
1802	53,937	5228	445,094	110	18	
1803	60,566	5616	533,910	122	0	
1804	64,637	5374	570,840	136	5	
1805	78,452	6234	862,410	169	16	
1806	79,269	6863	730,845	138	5	
1107	71,694	6716	609,002	120	0	9·1
1808	67,867	6795	495,303	100	7	
1809	76,245	6821	770,028	143	12	
1810	66,048	5682	569,918	132	5	
1311	66,499	5948	563,742	126	0	
1812	75,510	7248	608,065	113	0	
1813	86,713	8166	685,572	113	0	9·5
1814	87,482	7936	766,824	128	0	
1815	79,984	6607	582,108	121	0	
1816	83,058	7045	541,737	109	0	
1817	75,816	6608	422,426	96	0	
1818	80,525	6714	587,977	121	0	
1819	93,234	7214	728,032	136	0	8·1
1820	92,672	7364	620,347	119	0	
1821	98,803	8168	628,832	111	0	
1822	106,723	9331	676,285	104	0	
1823	97,470	8070	618,933	110	0	
1824	102,200	8022	603,871	110	0	
1825	110,000	8417	743,253	124	0	7·9
1826	118,768	9140	798,790	133	0	
1827	128,456	10,450	755,358	106	0	
1828	130,866	9961	759,175	112	7	
1829	125,902	9763	525,834	109	14	
1830	135,665	10,890	784,000	106	15	
1831	146,502	12,218	817,740	99	18	
1832	139,057	12,099	835,812	104	14	
1833	138,300	11,185	858,708	110	0	

	Tons of Ore sold.	Fine Copper in Ore.	Money value.	Standard.		Per cent. yield.	No. of Mines selling Ores at the Ticketings.
			£	£	s.		
1834	143,296	11,224	887,902	114	4	7·9	
1835	153,607	12,271	896,401	106	11		
1836	140,981	11,639	957,752	115	12		
1837	140,753	10,823	908,613	119	5		
1838	145,688	11,527	857,779	109	3		76
1839	159,551	12,450	932,297	110	2	7·8	79
1840	147,266	11,037	792,758	108	10	7·5	79
1841	135,090	9987	819,947	119	6	7·4	79
1842	135,581	9896	822,870	120	16	7·3	70
1843	144,806	10,926	804,445	110	1	7·5	64
1844	152,667	11,246	815,246	109	17	7·4	68
1845	157,000	12,239	835,358	103	10	7·8	77
1846	158,913	12,447	886,785	106	8.	7·8	88
1847	148,674	11,966	830,739	103	12	8·	92
1848	155,616	12,869	825,080	97	7	8·3	90
1849	144,938	12,052	716,917	92	11	8·3	89
1850	150,890	11,824	814,037	103	19	7·8	72
1851	154,299	12,199	808,244	101	0	7·9	76
1852	152,802	11,706	828,057	106	12	7·6	82
1853	180,095	11,839	1,124,561	136	16	6·5	94
1854	180,687	11,779	1,153,756	140	2	6·6	96
1855	188,969	12,241	1,212,686	141	10	6·8	106
1856	206,177	13,533	1,241,835	133	13	6·6	134
1857	191,798	12,177	1,201,270	...		6·3	
1858	182,391	11,831	1,057,534	131	14	6·5	123
1859	183,944	11,888	1,079,075	133	6	6·4	120

The United Kingdom produced in 1858, from the 164 copper mines that are reported, 226,852 tons of ore, valued at £1,336,535, which contained 14,456 tons of fine copper, valued at £1,562,693. The total quantity of copper produced from British, Foreign, and Colonial ores during the same year, was 31,611 tons, valued at £3,417,149.

In the year 1858 the various smelting companies purchased ores and regulus as follows:—

	Tons.
Mines Royal Company ...	10,846
Vivian and Sons	53,992
Freeman and Co.	9,319
Pascoe Grenfell and Sons	34,204
Sims, Willyams, and Co.	27,017
Williams, Foster, and Co.	51,214
Mason and Elkington ...	24,463
Frederick Bankart	12,873
Copper Miners' Company	15,485
Charles Lambert	9,823
Newton, Keats, and Co.	1,929
Alkali Company	526
Briton Ferry Copper Company	2,065
British and Foreign Copper Company	2,499
Pocket Nook Smelt Company....................	551
Mona Mining Company...	485

The imports of copper during the year 1858 were, according to Parliamentary returns, as follows:—

	Tons.
Copper ore	78,641
Regulus	18,458
Unwrought in bricks, &c.	3,919
Old copper	952
Copper part wrought in bars.....................	2,495
Plates and Coin	135
Copper manufactures ...	1,068

Coming principally from Chili, Cuba, Spain, Australia, and the United States.

The total amount of metallic copper exported during the same period was 24,788 tons, 5819 tons of which went to the British East Indies as sheets, nail, and yellow metal, and 4456 tons to France and Belgium in the form of unwrought bricks and pigs.

According to the circular of Messrs. Dupee, Beck, and Sayls, the produce of the Lake Superior region in 1859, amounted to 4,200 tons of ingot copper, valued at about £400,000.

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